Author:
Wilson, Gavin John

Title:
Patterns of population change in the Eurasian badger (Meles meles) in Britain, 1988-1997.

PATTERNS OF POPULATION CHANGE IN THE EURASIAN BADGER (*MELES MELES*) IN BRITAIN, 1988-1997

GAVIN JOHN WILSON

A dissertation submitted to the University of Bristol in accordance with the requirements for the degree of Doctor of Philosophy in the Faculty of Science

School of Biological Sciences

August 1998

ABSTRACT

In this thesis, the patterns of population change in the British badger (*Meles meles*) population over a nine year period are presented. The results of a stratified, random survey undertaken between October 1994 and January 1997 were compared with those from an identical, baseline survey which was carried out between November 1985 and early 1988. 1-km squares were the unit of survey: 2271 1-km squares were surveyed twice - once in the 1980s survey and again in the 1990s. The Institute of Terrestrial Ecology's Land Classification Scheme was incorporated into the survey design to ensure that Britain's landscape types were evenly represented in the sample, and to facilitate reliable extrapolation to the whole country.

There were estimated to be 50,241±4327 badger social groups in Britain in the 1990s, an increase of 24% from the original survey. Average group size also increased. An estimate of relative abundance, based on a field sign index which was quantified for each sample 1-km square, revealed that there had been an increase in badger numbers of 75% between the surveys.

Variables relating to habitat availability and persecution levels were recorded in both surveys. Changes in badger abundance were analysed with respect to changes in these variables between the two surveys. A decline in levels of persecution correlated with the increase in badger numbers. Tightening of the badger protection laws is believed to have brought this about.

The relationships between badger group size, sett size and activity, and latrine use were investigated to further refine the survey results, and to provide a means to estimate badger numbers at a local scale. Social group size was found to be related to the number of active holes at the main sett. A predictive model was produced incorporating main sett active holes and latrine use within territories.

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor, Professor Stephen Harris, for employing me to coordinate the national badger survey, and allowing me to extend the study into a Ph.D. project. I am grateful to the Peoples Trust for Endangered Species, who funded the badger survey and paid my salary for three years. I am also grateful to the many people who gave up their time to survey 1-km squares, and without whom collation of such an impressive database would have been impossible. I must thank in particular Martha Harris who carried out the laborious task of processing the many hundreds of completed maps, without once complaining. The members of the mammal research group, past and present, provided a friendly and supportive environment in which to work, for the whole period of the study.

Nicola Padden undoubtedly kept me sane during the seemingly endless months 'on the road' on fieldwork, and I thank her for her tolerance, support and love during that time.

I must thank Gillian Woolhead for her consistently amusing companionship, and for going abroad when I really needed to get some work done!

Finally, I would like to thank Mum, Dad and Phil back home for their continuing love and friendship, which I can always rely on.

DECLARATION

I declare that the work in this dissertation was carried out in accordance with the Regulations of the University of Bristol. The majority of the data contained in this thesis were collected as part of the second national badger survey, funded by the Peoples Trust for Endangered Species, with the assistance of volunteer surveyors. The findings were published in a refereed report which forms the basis of the dissertation - see Appendix 11.12. The vast majority of the work contained in the report was my own. In the latter stages of the survey report preparation, Graeme McLaren assisted with computer modelling and data handling, and Stephen Harris provided input in terms of discussion and report style. I carried out further analyses of these data subsequent to the report publication, the findings of which are detailed in the dissertation. For comparative purposes, data from the first national badger survey, carried out by Penny Cresswell, Stephen Harris and Don Jefferies were utilised. With these exceptions, I declare that the work in this thesis is my own.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

Gavin J. Wilson

Gavin Wilson

30 August 1998

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

1.1 *The study of animal abundance*

The study of animal abundance is concerned with the relationships between the regulatory factors which restrain the size of a given population, and the innate potential of that population for growth. Given limitless resources and lack of natural suppression of numbers, animal populations have the potential for exponential growth. In nature, this potential is not reached due to limitations imposed by many factors, such as food and habitat availability, competition for resources, predation pressure, parasite impacts, and stochastic environmental factors. The abundance of any given species at any one time is a product of the multifarious interactions of these factors. In recent history, the impact of human activities has become an important limiting factor to many species, often in a form analogous to predation, or alternatively via habitat loss. When the various factors affecting birth rates, death rates, emigration and immigration rates produce a population which is stable, an equilibrium is said to have been reached (Elton, 1930). In a stable environment, populations fluctuate to a greater or lesser extent around this level as a result of perturbations or random variations in these rates.

Changes in the abundance of a species can be brought about by variations in the relative effects of these factors, and the magnitude of the change depends in part on the sensitivity of the population to fluctuations in them. This can lead to increasing or decreasing abundance. A classic example of such fluctuations due to the influence of extrinsic factors is that of the mule deer (*Odocoileus hemionus*) on the Kaibab plateau in North America. In 1906 there were an estimated 4,000 deer, which rose to over 100,000 by 1924. Two years later this number had fallen back to around 40,000 animals (Lack, 1954). The increase in numbers was brought about by the extermination of predators and the prohibition of hunting. The subsequent decline was caused by a shortage of food. The considerable swings in the abundance of this species illustrate the capacity for animal populations to change in response to changing conditions, and in particular the repercussions of intervention by man. Perhaps the most striking example of the potential impact of man on animal numbers is the example of the American passenger pigeon (*Ectopistes migratorius*) last century. From the position of being considered one of the most abundant species of bird in the world at the turn of the century totalling an estimated nine billion birds, it was hunted out of existence in less than a century (McClung, 1993).

As awareness of conservation issues has grown throughout the latter half of this century, so has the need to hold reliable information on the status of species. The key requirement in studies of animal abundance is the ability to estimate numbers, and thence to monitor changes. The most direct way to find out how many individuals are living in an area is to count them. An example of this is human population census. This is impractical for most species at a large scale, therefore sampling techniques with extrapolation must be employed. A wide array of sampling methods are available and the correct method depends on a number of attributes of the species under investigation, the requirements of the study, as well as the resources available to carry it out. Perhaps the most important element of any monitoring scheme is that it can be repeated exactly, and that results from follow up surveys are standardised and are directly comparable. An illustration of the need for this are the game bag records kept by the Game Conservancy. They were until recently the only source of data on how numbers of selected mammal species in Britain were changing (Tapper, 1992). Although useful, the long-term trends observed in their records have to be viewed with respect to changing levels of 'sampling effort': changing gamekeeper strategy and numbers. These factors are often difficult to separate. For example, game bags of weasels (*Mustela nivalis*) over the last 40 years have declined steadily and consistently (Tapper, 1992). The reasons for this were unclear, and a number of possibilities were cited, such as changing land use or effects of rodenticide poisoning. However, recent research (McDonald & Harris, in prep.) has shown that the factor which most strongly affected size of the weasel bag was trapping effort by gamekeepers, which has declined on average over the same period. The declining trend in weasel numbers has been, at least in part, an artifact of the sampling regime.

Birds in Britain have received more attention than any other faunal group, and structured monitoring has continued over many years. The British Trust for Ornithology has for several decades been carrying out the Common Bird Census throughout Britain. In this scheme a network of skilled fieldworkers monitor pre-selected plots each year, and the results pooled to track any changes in common bird abundance. Through this monitoring scheme, changes in the populations of many of our bird species have been observed. An important example is that of the skylark (*Alauda arvensis*). Although retaining an unchanged distribution, its numbers are thought to have declined by over 50%. Without such a monitoring scheme, this would have remained unquantified and perhaps unnoticed. This 'early warning' has sparked scientific research into reasons for its decline, with resultant recommendations for changes in farming practice (Poulsen, *et al.*, 1998).

In terms of government policy, Britain is obliged under a suite of Directives, from Rio through to the E.U. Birds and Habitats directives to protect and enhance many species and the habitats they depend on. The UK Biodiversity Action Plan outlines a preliminary list of species that we are required to monitor, and provides action plans for some of them designed to secure their future. In order to be successful in this task, it is necessary to be fully aware of the status of the species of interest. Recently, properly structured national monitoring schemes have been put in place for some species of British mammal. For example, a third otter (*Lutra lutra*) survey of England reported the success of the otter population, since the original survey 20 years ago. The patterns of the recovery since a crash in the late 1950s could be assessed only through the analysis of the data provided by the survey. The continued success of the population is in part due to population strengthening programs which are carried out in key areas identified by the scheme (Strachan & Jefferies, 1996). In May 1998 year, a review describing the results of a major consultation exercise aimed at developing a framework for the future monitoring of Britain's mammals was published (Macdonald, Mace & Rushton, 1998). The document describes the potential sampling structures and methodologies which would be required to fulfil the aims of abundance estimation and trend tracking.

A standardised sampling regime is not burdened with the bias problems associated with game bag data. The basic technique most commonly used in ecological sampling, and which is proposed as the unit of survey in the aforementioned consultation document, is quadrat sampling. In quadrat sampling, all the individuals in several quadrats of known area are counted, and the average extrapolated to the whole area. For this technique to succeed, the population of each quadrat must be known exactly, the area of each quadrat must be known, and the quadrats must be representative of the whole area of interest (Krebs, 1985). The survey protocol used in this project is based on quadrat sampling theory.

1.2 The badger

The Eurasian badger (*Meles meles*) is a fossorial carnivore which spends long periods of time below ground in extensive burrow systems called setts. In most of Britain it lives in social groups which tend to be based in large, permanent main breeding setts. Although a carnivore, it has a catholic diet which is omnivorous in nature, being able to take various fruits, cereals, invertebrates and carrion (Kruuk, 1978a). In Britain, the badger has no natural predators, although this role has effectively been filled by man. The historical patterns of badger abundance appear to be closely linked to human activities. As in a number of European countries, for up to 200 years there has been systematic suppression of badger numbers nationwide due to the effects of control by landowners who have perceived badgers as a pest. It has been believed that badgers pose a threat to livestock, damage crops, and take eggs on game estates. Traditional means of control include trapping, snaring, gassing and shooting. Badgers have also been targeted for "sport" i.e. the old pastime of badger baiting and the more recently banned badger digging in particular. Badger digging is known to continue today (Griffiths, 1992), and its impact is discussed in this thesis.

1.3 The history of badgers in Britain

Badgers were generally perceived to be rare and in danger of local extinctions in the latter half of the 19th century. At the turn of the century local naturalists reported that badgers were rare or uncommon in many parts of England and that they were sparsely distributed in Scotland. The status of badgers at that time is summarised in the Victoria County Histories (Cresswell, Harris & Jefferies, 1990) and by a number of other authors e.g. Pease (1898) and Millais (1905). The rarity of badgers was probably the result of persecution and, in particular, widespread predator control by gamekeepers. In 1911, there were 22,000 gamekeepers in Britain (Potts, 1980), and badger control was part of their duties. However, during and after the 1914-1918 war, the intensity of predator control declined, due to a reduction in gamekeeping pressure, and many species of carnivore started to recover, including badgers. (Thorburn, 1920; Langley & Yalden, 1977). By the 1930s and 1940s, they appeared to be more common than earlier in the century (Neal 1990).

Since badgers did not undergo the extensive range reduction shown by other persecuted carnivores (Langley & Yalden, 1977), it is difficult to assess the impact of persecution on badger numbers in the years preceding the First World War. Cresswell, Harris & Jefferies (1990) concluded that the impact of gamekeepers on badger numbers was less dramatic than for other carnivores, and considered it unlikely that badger numbers had really increased dramatically following the First World War.

That assessment was based on prevailing knowledge of badger behavioural ecology. Badgers were described as contractionists (Kruuk & Macdonald, 1985). One feature of such species was that they would not expand their territories to encompass nearby suitable habitat but would maintain a constant territory size irrespective of changes in neighbouring social groups. This view was, in part, based on a long-term field study at Woodchester Park, Gloucestershire, where it took nine to ten years for a high-density badger population to recover to their former density following the removal a number of social groups (Cheeseman *et al.*, 1993). Therefore, Cresswell, Harris & Jefferies (1990) concluded that any badger population changes following a reduction in pressure from gamekeepers and other forms of persecution would lead to only a slow recovery and expansion into new areas. Other studies that reinforce this view include that carried out by Roper (1993), who concluded that setts, and particularly main breeding setts, are a valuable resource that cannot easily be replaced. He argued that offspring stand to gain more from remaining in their natal group and inheriting the parental sett than from leaving and constructing new setts of their own. This again predicts slow expansion of badgers into new areas.

In East Anglia, badger control, particularly by game keepers has remained conspicuous until recently. The number of active main setts in the region appeared to track the number of gamekeepers since the early 1900s, and it was estimated (Harris 1993) that the numbers of badger social groups in Norfolk and Suffolk were depressed to as little as one tenth of the level that was observed in neighbouring, comparable counties. Clearly, persecution by man can have a considerable effect on the abundance of badgers in Britain.

1.4 Previous Badger Survey Schemes

In 1963, The Mammal Society instigated a national system for recording badger setts, and this led to a plethora of mammal reports describing the status of badgers on a county or local basis. The national results are summarised by Neal (1972) and Clements, Neal & Yalden (1988). This database provided an invaluable source of information on the abundance and distribution of badgers across the country, and the typical habitats and substrates where badger setts were found. The database has been used subsequently as a baseline by which to monitor the fate of badger setts, and the common threats to their existence. In Essex, Skinner, Skinner & Harris (1991a) found that in the twenty-year period up to the mid-1980s, 36% of the 574 badger setts recorded by Cowlin (1972) had disappeared, with agricultural activities being the main identifiable cause of sett losses.

Whilst very valuable, an improved understanding of badger biology had highlighted limitations with The Mammal Society's database for monitoring future changes in badger populations. In their survey, recorded setts were not classified into different types. The relationship between numbers of setts and numbers of badgers is complicated, and it is not possible to infer badger numbers from sett numbers *per se*. There were no data from areas where setts where absent, so the rate of colonisation of new areas could not be quantified (Cresswell, Harris & Jefferies, 1990). Also, the quality and quantity of the data from each county were determined by the enthusiasm of the local recorder. In order to improve upon the database that was available for monitoring badger population changes, the Nature Conservancy Council funded a new badger survey in the 1980s, coordinated at Bristol University. The survey was structured in such a way as to make possible extrapolations of the results to the whole country, and provide a baseline by which future repeat surveys could be directly compared. I coordinated the first repeat of this survey in the mid-1990s, after a 9 year interval from the original. Much of this thesis is concerned with documenting comparisons between the results of the two surveys.

1.5 The 1980s badger survey

The aims of the 1980s badger survey were:-

a. To provide a baseline against which any future changes in badger numbers could be assessed.

b. To quantify the habitat requirements and sett site characteristics for badgers in different parts of Britain.

c. To undertake a stratified survey so that the results could be extrapolated to estimate badger distribution and density throughout Britain.

d. To compare the potential and actual badger populations in Britain, and to calculate the effects of land-use changes, persecution and control operations on badger numbers.

To achieve these goals, a stratified random sample of 1-km squares were surveyed for badger setts and signs of badger activity (see Chapter 2). Badger densities were presented for each of the 32 land classes, and the number of badger social groups was estimated to be 42,891±3851 (Cresswell, Harris & Jefferies, 1990). Assuming a mean of 5·9 adult badgers per social group, this was estimated to equate to approximately 250,000 adult badgers. The population was not evenly distributed throughout Britain; 24·9% were in south-west England and 21·9% in south-east England, whereas only 14·0% were found in Wales and 9·9% in Scotland (Cresswell *et al.*, 1990).

1.6 Other national badger surveys

Following the publication of the results of the British survey, the same approach was used to determine the number of badger social groups in Northern Ireland (Feore, Smal & Montgomery, 1993; Feore, 1994) and in the Irish Republic (Smal, 1995). Data collection was exactly as developed in Britain, except that unlike the British survey large numbers of volunteers were not used. Also, there was no national land class system available in Ireland, and so instead the 1-km square in the extreme south-west of each 10-km square was surveyed. This gave approximately a one percent coverage, as in the British survey, but the lack of stratification meant that extrapolating the results was potentially more problematic.

Both the Irish surveys were undertaken in habitats similar to those in Britain where there were comparable badger densities. The same approach is now being used in Lithuania, where badger densities are much lower, and habitats somewhat different. However, progress to date suggests that the approach will be equally successful (Eduardas Mickevicius, *pers. comm.*).

The overall status of badgers in western Europe was reviewed by Griffiths & Thomas (1993). They concluded that badger populations were either stable or increasing throughout much of Europe, and that they appeared to be particularly abundant in Britain, Ireland and Sweden. Only the populations in Albania and parts of the former Yugoslavia appeared to be decreasing. They considered the badger population in Britain to be stable. In their review of the status of British mammals, Harris *et al.* (1995) reinforced the view that the badger population in Britain was important from a European perspective. Thus, it is important to monitor any badger population changes in Britain carefully.

1.7 The different categories of badger sett

Since badger setts were the primary unit of the surveys, it is important that the functional differences in sett types used by badgers are understood. The sett classification scheme used in the original 1980s badger survey was based on the apparent functional differences of sett types maintained within group territories. It was considered that differential patterns of change in the different sett categories would reflect different population change patterns. The most important category is the main sett (Kruuk, 1978b; Cheeseman *et al.*, 1981; Harris, 1984).

Main setts are the primary breeding sett for the majority of badger social groups, and are considerably larger than other categories of sett, in terms of total tunnel length, number of chambers, number of entrance holes and size of spoil heaps. They are also in continuous use by the badger group.

Roper (1992a; 1992b) showed that setts of different size and status are built according to the same basic architectural principles, despite main setts often being much larger. He argued that suitable sites for main setts were limited, and they are an important resource. He went on to suggest that main sett availability may be an important pressure in the evolution of sociality and territoriality in badgers (Doncaster & Woodroffe, 1993; Roper, 1993). Thornton (1988) produced a formal framework for classifying badger setts into four different types. These were: main, annexe, subsidiary, outlier and disused main. Annexe setts are effectively extensions of the main sett, but are not connected underground. They are, by definition, close to main setts. Cresswell *et al.* (1992) showed that the proportion of sows in a social group that breed increased with the number of annexe setts associated with the group. The increased reproductive output by the social group was a function of the number of younger sows whose blastocysts implant, rather than an increased proportion of sows carrying blastocysts. Since the presence of annexe setts correlates with increased productivity by younger sows, the presence of annexe setts was believed to facilitate avoidance by younger sows of aggression from older ones. Aggression levels between sows appears to be high, and neo-natal losses due to infanticide were estimated to be 35% by Cresswell *et al.* (1992) and 42% by Page, Ross & Langton (1994). Subsidiary setts and outlier setts are similar in function, but are distinguished on the basis of size. Both categories appear throughout badger territories and are not usually connected by a path to the main sett. Therefore they are not considered part of the main sett complex in the way that annexe setts are. They are both used periodically throughout the year, and act as temporary refuges; they are rarely used as breeding sites by social group members. Outlier setts are very small, consisting usually of one or two holes with small spoil heaps, whereas subsidiary setts are larger.

Roper & Christian (1992) monitored the behaviour of a single group of badgers over an eight-month period (September to April). They found that two females rarely slept away from the main sett, whereas a third female and the two males used "outliers" (they did not distinguish between subsidiary and outlying setts) most frequently in the spring and autumn. Of five animals, no individual slept in "outliers" on more than 50% of the days for which data were available, and the overall frequency of "outlier" use, averaged over the whole period across all five animals, was 26% of days. The main sett was the only sett that ever contained all the members of the social group at the same time, and was the primary sett used for overwintering. It was shown in one study that when slightly disturbed, badgers made their way back to the main sett, but if badly disturbed, they bolted for the nearest sett, irrespective of its category (Roper & Christian, 1992). Outliers and subsidiaries were also apparently used as rest sites during foraging sessions. Although not directly related to badger numbers in a territory, it seems intuitively obvious that if there are more badgers occupying a given territory after an interval of ten years, it is likely that there will be more outlying and/or outlier setts.

Other studies have shown that main, and often annexe setts are in continuous use in contrast to the intermittent use of subsidiaries and outliers (O'Corry-Crowe, Eves & Hayden, 1993). This is reflected by the levels of activity shown at the different sett types: in the original

1980s survey, 48% of holes at main setts were classified as well used, 34% of holes at annexe setts, and only 24% of holes for both subsidiary and outlying setts (Cresswell, Harris & Jefferies, 1990).

Main setts and indeed entire territories can be completely abandoned. Badgers are known to desert setts when disturbed, (Harris *et al.*, 1994; Harris, 1994) but the remains - holes, spoil heaps etc. can remain visible for some considerable time. Badgers also occasionally relocate to new sites, sometimes considerable distances, for no obvious reason (Sleeman, 1992). Therefore the category of disused main sett was included as a variable in the data collection. Disused main setts were regularly recorded in the 1980s badger survey, and the proportion of disused to active main setts increased with declining density of social groups (Cresswell, Harris & Jefferies, 1990).

The 1980s survey showed that each badger social group had, on average, 4·10 setts i.e. one main, 0·43 annexe, 0·86 subsidiary, 1·57 outlying and 0·24 disused main setts. In the Republic of Ireland, the pattern of sett distribution per social group was remarkably similar, with 4·09 setts per social group, these comprising one main, 0·50 annexe, 1·32 subsidiary, 1·08 outlying and 0·19 disused main setts (Smal, 1995). The relative abundance of the different sett types per social group was also similar in Northern Ireland, but there were slightly more setts (5·49) per group i.e. one main, 0·72 annexe, 2·04 subsidiary, 1·60 outlying and 0·13 disused main setts (Feore, 1994). The consistency of these results suggested that, for the reasons outlined above, the sett definitions are biologically meaningful, and that different sett types do indeed have specific functional roles. The guidelines used in the surveys for placing setts into these categories are shown in Appendix 11.1.

1.8 Monitoring badger population changes

Badger population changes can occur in two ways: there can be an increase (or decrease) in the number of social groups, and/or there can be an increase (or decrease) in the size of social groups. These may occur in parallel or independently. For example, at Woodchester Park in Gloucestershire, the Ministry of Agriculture, Fisheries and Food intensive badger study site, the number of social groups has remained constant (at 21), but there has been a steady increase in mean group size, which more than doubled in about a decade (Neal & Cheeseman, 1996).

Changes in the number of social groups and the size of social groups have different implications. The general perception is that the number of social groups increase only slowly, particularly in areas of high population density (Neal & Cheeseman, 1996), and that even when social groups are removed from such areas, recolonisation is a protracted process, due to the aspects of badger behavioural ecology outlined in section 1.3. Whilst such changes may be slow, an increase in the number of social groups is likely to reflect a long-term and more permanent increase in badger population size.

Even in areas where badgers are not persecuted, adult mortality is around 20% per annum (Harris, Cresswell & Cheeseman, 1992), and cub mortality, including pre-emergence losses, is much higher. Factors that affect either adult or cub mortality rates would lead to changes in social group size; these could be either long or short term. For instance, reducing the levels of persecution, thereby reducing adult mortality rates, could lead to a long term growth in social group size. In contrast, adverse weather patterns, particularly if they last only one or two years, may lead to a short term decline in group size. Hot dry summers can lead to high levels of cub mortality due to starvation (Neal & Cheeseman, 1996). In fact, following particularly unfavourable summers, entire cohorts can disappear from the badger population (Cheeseman *et al.*, 1987). Longer term changes in weather patterns could, however, lead to more significant population changes. The weather in Britain is variable, but the current scenario for climate change is for mean temperatures to rise, for extremely warm seasons and years to occur more frequently, and for summer precipitation to decrease in southern Britain (Anon., 1996). Thus the trend is towards unfavourable weather conditions detrimental to the survival of badger cubs (Neal & Cheeseman, 1996). A weather trend in this direction would lead to a succession of years with poor cub recruitment, and hence reduction in mean group, and therefore population size.

1.8.1 Changes in the number of badger social groups

In this project, changes in the number of active main setts are used to provide a measure of changes in badger social group number, which indicate long-term trends in the badger population (Cresswell, Harris & Jefferies, 1990).

1.8.2 Changes in the number of badgers

Badger social group size can be very variable (Cheeseman *et al.*, 1987), and so monitoring trends in badger numbers is more difficult than monitoring the number of social groups. In the 1980s survey, Cresswell, Harris & Jefferies (1990) assumed a mean of 5·9 adults per social group. This was based on a small number of studies, and at the time provided the best estimate available of mean social group size. Whilst it may have been a reasonable ssumption for some areas of Britain, Cresswell, Harris & Jefferies (1990) accepted that social group size was likely to be smaller in low density areas.

In this thesis, a field sign index is used to estimate change in the relative abundance of badgers nationally, to complement the results of the changes in sett numbers.

1.9 Thesis aims and structure

The aim of this thesis is to analyse the results of the second national badger survey coordinated by myself in the mid-1990s, with respect to the results obtained in the original 1980s survey. The two databases are used to address the following issues.

a. To determine whether there had been any changes in the number of badger social groups in Britain and to identify any regional and landscape differences in the pattern of change.

b. To determine whether there had been any changes in the number of badgers in Britain and to identify any regional and landscape differences in the pattern of change.

c. To determine whether there had been any changes in the levels of badger persecution and, in particular, sett disturbance in Britain, and any regional and landscape differences in the pattern of change.

d. To determine any changes in the habitat preferences of badgers in Britain in response to changes in habitat availability.

e. To determine how changes in persecution levels and habitat availability could have led to any badger population changes.

Chapter two describes in detail the structure, field protocol and data collation processes for the surveys. Chapter three analyses the patterns of change in the distribution and abundance of badger setts in Britain, both by landscape type and on a regional basis. The implications of these changes for the badger population are discussed. Chapter four presents an analysis of the change in relative abundance of badgers in Britain, based on the field sign index collected during the survey. Aspects of badger behavioural ecology implied by the results, in terms of colonisation patterns are discussed. Chapter five presents the results of a pilot study carried out separately to the survey, quantifying the relationship between badger numbers and sett numbers, size and activity. The results are used to refine the national survey output. A field method for estimating the size of badger social groups is investigated. Chapter six analyses the importance of habitat availability for badger sett distribution, and whether changes in land use have influenced the patterns of population change. Chapter seven investigates the changing levels of persecution observed between the two surveys, and the effect on badger numbers. Chapter eight uses computer modelling to elucidate the possible underlying mechanisms driving the changes in the population. Chapter nine presents a general discussion on the findings of this project.

2. Methods

In this Chapter, the methods used in the data collection, interpretation and analyses of the repeat national badger surveys are discussed. The methods described here are the basis for Chapters three, four, six and seven of this thesis. The methodology for the separate field study described in Chapter five is outlined in section 5.2, and the modelling methodology is presented in section 8.2.

2.1 The survey design

Selecting the best survey design is crucial to the success of a wildlife monitoring scheme such as this. Detailed discussion on the considerations of this are presented in Appendix 11.6. The national survey was set up as a stratified, random sampling scheme, with repeated samples design. 1-km squares were the unit of survey.

2.2 The stratification

The aim of the monitoring scheme protocol was to take a representative sample of Britain's main landscape types, in order to make useful extrapolations when estimating national trends. To this end, the Institute of Terrestrial Ecology's Land Classification Scheme was incorporated into the survey design. In this scheme, the 1-km squares which make up Britain's Ordnance Survey grid are grouped into functionally similar classes. The scheme is summarised by Bunce *et al.* (1996). The scheme was in its infancy at the time of the original badger survey. The initial classification in 1977, which was used for the 1980s survey, was based on 281 attributes describing the climate, topography, human geography, solid geology and drift, in each 1-km square. Indicator Species Analysis (Hill, Bunce & Shaw, 1975) was used to classify a sample of 1212 1-km squares from across Britain into 32 groups, which were called Land Classes. To improve the estimates of the relative size of each land class in Britain, a further 4800 1-km squares were assigned to land classes using 76 key indicator attributes. Thus approximately 6000 1-km squares were allocated to a land class. In the original badger survey, 2455 1-km squares were surveyed, which were randomly selected from this grid. Subsequent to the original badger survey, the Institute of Terrestrial Ecology assigned every 1-km square in Britain to a land class, using a smaller number of key indicator attributes, based on the experience of the initial scheme (Bunce *et al.*, 1997). The other important and useful development since the original badger survey was that the land classes were grouped into four strata for interpretative purposes (Barr *et al.*, 1993). The land class groupings developed by Barr *et al.* (1993) reflect the ecological characteristics and the most widely used relationships between the classes, with the overall ranking determined by the first axis of the principal component analyses of the land cover data recorded in a sample of eight 1-km squares from each of the 32 land classes surveyed in 1978 (Bunce *et al.*, 1996).

At the broadest level, the 32 land classes are aggregated into four basic groups based on the dominant land cover; these are the "arable", "pastoral", "marginal upland" and "upland" land class groups (Barr *et al.*, 1993; Bunce *et al.*, 1996). The basic characteristics of these four major land class groups are summarised by Bunce *et al.* (1996). The arable land class group at the next level is further divided into three groups, the pastoral land class group into two groups. Recent surveys on brown hares (*Lepus europaeus*) (Hutchings & Harris, 1996) and on bats and habitats (Walsh, Harris & Hutson, 1995; Walsh & Harris, 1996a; 1996b) used these seven land class groups to analyse their data (Table 2.1). This approach proved to be highly successful because the seven groups reflected differences in patterns of land use that were of greatest relevance to predominantly lowland species of mammal; their distributions are shown in Figure 2.1

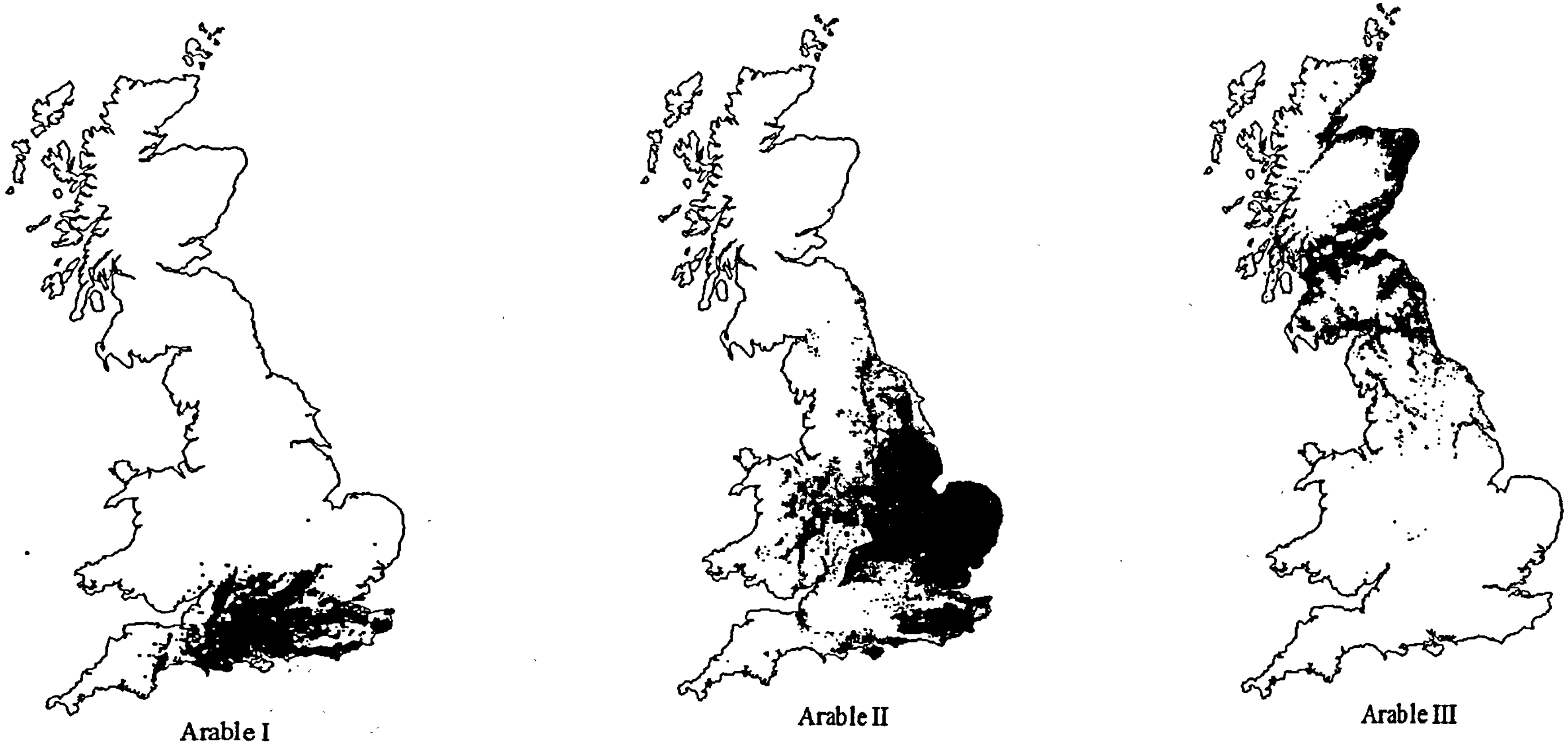


Figure 2.1 Distribution of the three Arable land class groups

Pastoral IV

Pastoral V

Figure 2.1 (cont.) Distribution of the two Pastoral land class groups

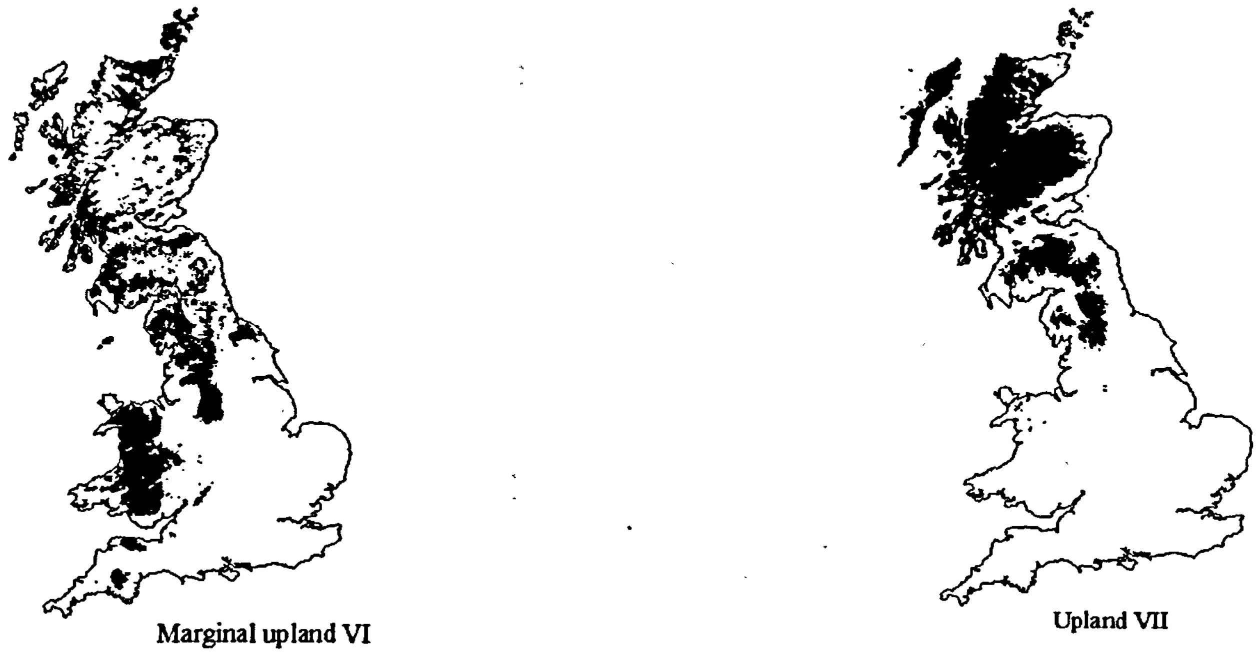


Figure 2.1 (cont.) Distribution of the Marginal upland and Upland land class groups

Table 2.1 The number of 1-km squares in each land class group, and the number (percent) of squares surveyed from each group.

Land class group	Number of 1-km squares in group	Number of squares surveyed, 1980s (%)	Number of squares surveyed, 1990s	Percent repeated / resurveyed	Number of new squares surveyed in the 1990s
Arable I	14,460	233 (1.6)	208	89	30
Arable II	48,385	548 (1.1)	493	90	76
Arable III	18,339	198 (1.1)	188	95	22
Pastoral IV	34,730	470 (1.3)	428	91	55
Pastoral V	35,385	356 (1.0)	333	94	49
Marginal upland VI	35,438	349 (1.0)	335	96	65
Upland VII	45,150	301 (0.7)	286	95	10
Totals	**231,885**	**2455 (1.1)**	**2271**	**93**	**307**

These seven land class groups are used in this thesis to analyse badger population changes between the two surveys. This approach is particularly useful in highlighting patterns of population change in different landscape types. It also facilitates analyses of the patterns of habitat use by badgers within the different landscape types. However, within each land class group, there may be local differences in the patterns of change in the badger population as a result of a variety of anthropogenic factors. These may, for instance, be associated with different human population densities, proximity to urban areas, and historical factors, since badger digging and other forms of badger persecution are higher in some areas than others (Reason, Harris & Cresswell, 1993). Thus changes in the badger population are also presented regionally where these are considered appropriate, and where it is felt such presentation helps in understanding the patterns of change; the fourteen regions used for these analyses are described in Table 2.2. In defining these regions, wherever possible counties with generally similar land use, human population density, and/or past patterns of badger persecution, were grouped together.

Table 2.2 The regions used to analyse the badger population

Region	Number of 1-km squares in region	Counties
North England	15,815	Cleveland, Cumbria, Durham, Northumberland, Tyne and Wear
North-west England	7505	Cheshire, Gtr. Manchester, Lancashire, Merseyside
North-east England	15,620	Humberside, North Yorkshire, South Yorkshire, West Yorkshire
West Midlands	15,685	Gloucestershire, Hereford & Worcester, Shropshire, Staffordshire, Warwickshire, West midlands
East Midlands	13,351	Derbyshire, Leicestershire, Lincolnshire, Nottinghamshire
Central England	11,337	Bedfordshire, Buckinghamshire, Hertfordshire, Gtr. London, Oxfordshire, Northamptonshire
East Anglia	16,641	Cambridgeshire, Essex, Norfolk, Suffolk
South-west England	18,494	Avon, Cornwall, Devon, Dorset, Somerset
Southern England	9063	Berkshire, Hampshire, Isle of Wight, Wiltshire,
South-east England	9487	Kent, Surrey, East Sussex, West Sussex
North Scotland	48,738	Central, Fife, Grampian, Highland, Tayside
South Scotland	28,568	Arran Borders, Dumfries & Galloway, Lothian, Strathclyde
Mid and North Wales	11,734	Anglesey, Clwyd, Gwynedd, Powys
South Wales	9847	Dyfed, Mid Glamorgan, South Glamorgan, West Glamorgan, Gwent
Total	231,885	

2.3 The survey area

The 1980s survey covered mainland England, Scotland and Wales, plus Anglesey, Arran, Canvey Island, the Isle of Grain, the Isle of Sheppey and the Isle of Wight. This included all of the islands believed at that time to have established badger populations, but excluded those islands for which there were only occasional badger records; see Cresswell, Harris & Jefferies (1990) for a discussion as to why other islands were not included in the survey. Since the

1980s survey, there have been small changes in the recorded status of badgers on some of these islands. Foulness, for instance, was excluded because badger sightings were few, and records of setts were even fewer (Cresswell, Harris & Jefferies, 1990).

Badgers have also been recorded on the island of Skye since the 1980s survey (Roger Cottis, *pers.comm.*), but their numbers are thought to have undergone a steady decline over many years to their current low level. A number of factors may have contributed to this slow pattern of population decline. These include: the development of crofting communities last century; the activities of gamekeepers, the hunting of badgers for their valuable pelts; and, more recently, indiscriminate rabbit control. However, despite this widespread persecution, it appears that a remnant population has survived on the island. In April 1997 a badger was run over on the island and its body recovered. Thus, it would appear that badgers have persisted on Skye, although their numbers remain very low.

The results from Skye also suggest that badgers can persist at very low levels for extended periods; therefore, it may be that badgers have also survived on other islands or areas where they are currently believed to be absent. Whilst the recovery of such relict populations is important and should be carefully monitored, the number of active setts will be very low, and will contribute very little to the national population trends sought in this study.

2.4 Survey protocol

The fieldwork for the 1980s survey ran from 1 November 1985 through to early 1988. The repeat survey, coordinated by myself, started in October 1994 and was completed by January

1997. In both surveys, field work was largely confined to the autumn, winter and spring, when the vegetation was at its lowest, although some upland areas were surveyed in early or late summer.

The primary aim of the repeat survey was to cover the same 2455 1-km squares included in the 1980s survey. In addition, it was decided to survey a sample of new, previously unsurveyed squares to be used as a quality control check. These additional squares could be compared with the resurveyed 1-km squares to provide a check for any biases introduced by the repeated design methodology (see section 2.6). However, all analyses of patterns of change, and the badger population estimates are based only on the data from the resurveyed 1-km squares.

For both resurveyed and new 1-km squares, squares were surveyed according to standard protocol developed for the original 1980s survey, and were used by myself and the volunteer surveyors. Details were noted on standard recording sheets. This was entirely compatible with the original 1980s survey. The first section described how to record the badger data (Appendix 11.1), and explained how to categorise the setts into one of five types (main, annexe, subsidiary, outlying & disused main); the definitions of these sett types are given in Appendix 11.1. For each sett, the number of well-used, partially used and disused holes were recorded; the definitions of these are also given in Appendix 11.1. These details were recorded onto the form shown in Appendix 11.2. Two maps were also used to record the data; these were copies of the 1:25,000 Pathfinder series, enlarged to a scale of approximately 1:6250. One map was used to mark the position of each badger sett. On this map, the survey 1-km square was divided into nine sub-squares, and surveyors were asked to record the presence or absence of badger footprints, badger paths or runs, and dung pits in each of the nine sub-squares on the recording form (Appendix 11.2). This provided a measure of badger activity in each 1-km square.

The other instruction sheet detailed the habitat key (Appendix 11.3). The second map of each 1-km square was used to record the habitat data. All habitat areas within the 1-km square that were greater than 50 metres in length or 500 square metres in area were shaded, referring to the 40 different habitat types described on the key. Further details of this are given in Section 6.2.

One further instruction sheet and recording form were included for the repeated 1-km squares (squares surveyed in both surveys). This explained how to record any changes to the badger setts within the 1-km square since the 1980s survey (Appendix 11.4), and there was a recording sheet on which to record these changes (Appendix 11.5). It was essential to ensure that any changes were recorded accurately; each surveyor, therefore, was sent a copy of the badger data from the 1980s survey. Whilst it is possible that having the original data sheets could have biased the results by focussing the search effort to setts that had already been recorded, thereby missing any new setts, surveyors were given strict instructions to survey the whole 1-km square thoroughly. In addition, the whole 1-km square had to be surveyed to record the habitat data, and recorders were not sent a copy of the original habitat data. Having a copy of the original badger data was essential, since it enabled the surveyor to check the quality of the data recorded in the 1980s survey, to document any errors in the original data, and to determine whether a sett had fallen into disuse or disappeared, or had appeared since the survey in the 1980s. Possible biases associated with this approach are investigated in section 2.6.

2.5 Survey coverage

Of the 2455 1-km squares surveyed in the 1980s, 2271 (93%) were resurveyed in this current study. The distribution of the resurveyed squares is shown in Figure 2.2. In addition, 307 new 1-km squares were surveyed; their distribution is shown in Figure 2.3. The proportion of 1-km squares resurveyed and number of new 1-km squares in each county, land class and land class group are shown in Table 2.1 and Table 2.2 . The proportion of 1-km squares resurveyed was similar by region and by land class group, and there was no bias introduced by under-surveying particular areas or habitat types. Failure to resurvey 1-km squares was generally because of a lack of volunteers in the region, although 14 (0·6% of the original 2455) were not resurveyed because access was refused to all (nine) or part (five) of the 1-km square. In theory it is possible that access was refused because any setts on the land had been damaged or destroyed, or there had been some other form of illegal activity that the landowner did not want recorded. However, this was not considered to be a significant potential source of bias because badger setts were only recorded in the 1980s in five of the 14 1-km squares (35·7%) to which we were refused access. Of the total sample of 2455 1-km squares surveyed in the 1980s, 699 (28·5%) contained badger setts. Since access was refused to so few 1-km squares, and because this sub-sample was not skewed towards 1-km squares that held setts, there is no evidence that being refused access biased the survey results. Generally, there were few problems with obtaining permission to survey private land.

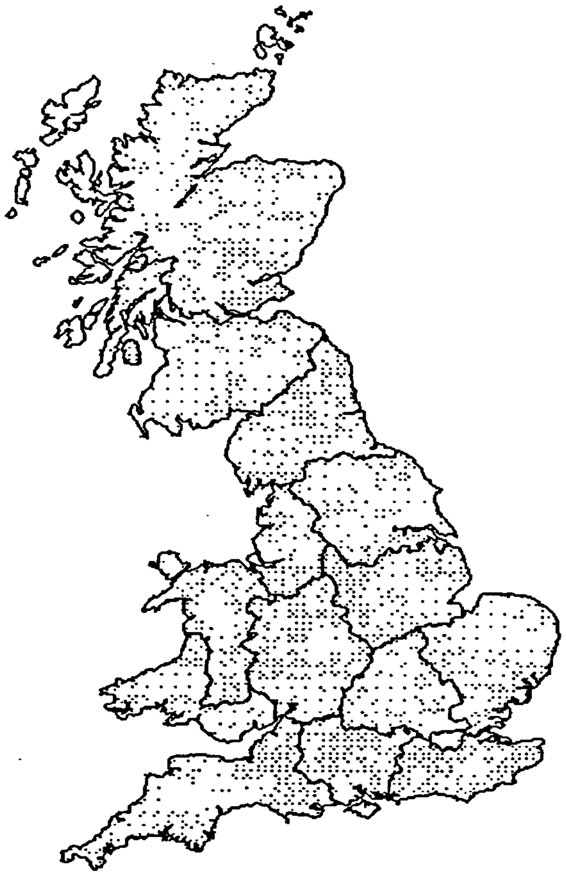


Figure 2.2 The distribution of the 2271 1-km squares which were surveyed in both the the 1980s and 1990s surveys

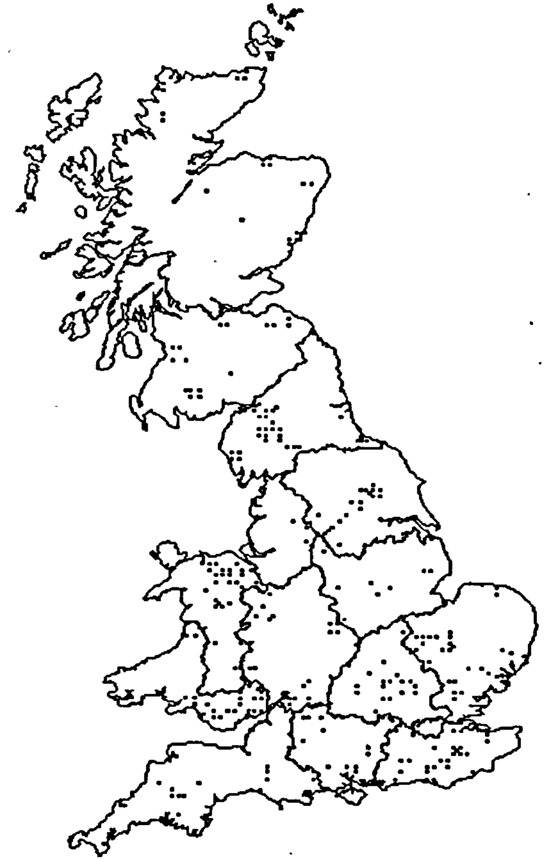


Figure 2.3 The distribution of the 307 1-km squares surveyed for the first time in the 1990s survey

2.6 Data checking

2.6.1 Ensuring comparability between the two surveys

For a repeated survey methodology such as this, it is important to ensure that the data were treated in exactly the same way during both surveys to ensure comparability. This was essential to ensure that we are measuring real change rather than differences in interpretation between the two surveys. To check that there were no differences between the two surveys, the full-time surveyor on the 1980s survey, Penny Cresswell Lewns, met with myself to standardise field data collection, and interpretation of the field data provided by volunteers.

2.6.2 Preliminary data sorting: quality check of volunteer surveys

On receipt, the completed forms and maps for each 1-km square were carefully checked by myself to ensure uniformity of approach for the survey work, and that all the data had been entered correctly. Those 1-km squares that were not clear, or for which some data were missing, were returned to the surveyor for completion. The sett classifications were then carefully checked against the other field data, and care was taken to ensure that the sett classifications were consistent between the 1980s and 1990s surveys. Where there was doubt as to whether a sett had been correctly classified, this was queried with the recorder and corrected if necessary. In both surveys, fewest problems were encountered with identifying main setts, and most problems were encountered by surveyors who had confused annexe and subsidiary setts. The habitat data were then checked to ensure that no improbable categories had been recorded; any queries were referred to the surveyor for clarification. Finally, the quality of the overall data collection was classified to one of the three following groups: a rating of "1" denoted clear field data with well-labelled maps and no queries; "2" denoted field data and/or maps that needed some care to interpret because there was ambiguity in the badger data that needed clarification, or the habitat data had not been fully completed, or the shading of the habitat types was such that the boundaries were not clearly defined; and "3" denoted data sheets and/or maps that were incomplete. In addition, there was a fourth category that denoted 1-km squares surveyed by myself. Sample sizes in each category in the 1990s survey were as follows: category 1 - 1067 (47%); category 2 - 357 (16%); category 3 - 110 (5%); and category 4 - 737 (32%). Thus overall only 21% of the resurveyed 1-km squares had queries that required clarification, and the quality of data collection was high. All the new 1-km squares were surveyed by volunteers; the quality ratings for these were as follows: category 1 - 209 (68%); category 2 - 79 (26%); and category 3 - 19 (6%).

The following tests were undertaken to determine whether there were differences in the quality of data between these four quality categories and, in particular, whether the volunteer surveyors collected data of a comparable standard with those collected by myself. First, the mean main sett density for each of these four data quality categories were compared within each of the six land class groups (Upland VII was excluded, because only very few main setts were found in that land class group: two in the 1980s and five in the 1990s). Kruskal-Wallis tests were used within each land class group; for five there was no difference in recorded main sett densities (Arable I, X^2=6·24, n.s.; Arable II, X^2=5·77, n.s.; Arable III, X^2=6·65, n.s.; Pastoral IV, X^2=3·66, n.s.; Pastoral V, X^2=4·17, n.s.). For Marginal upland VI, there was a significant difference (X^2=21·10, p<0·0001) because badger density was low, and most main setts occurred in the 1-km squares rated "1". Applying the same tests to all other sett types showed that there were no significant differences in three land class groups (Arable II, X^2=4·50, n.s.; Pastoral IV, X^2=7·36, n.s.; Pastoral V, X^2=7·38, n.s.). For the other three, there were differences. In Arable I ($X^2=9{\cdot}52$, $p<0{\cdot}05$) this was due to fewer setts in the 1-km squares surveyed by myself, who had surveyed a large number of squares from the Kent marshes and similar habitats where fewer setts would be expected. In Arable III ($X^2=15{\cdot}88$, $p<0{\cdot}005$), this was because the small number of 1-km squares rated "3" actually contained a greater number of setts. In Marginal upland VI ($X^2=28{\cdot}41$, $p<0{\cdot}0001$) this occurred because I concentrated on surveying the more remote upland 1-km squares where there was a lack of volunteer surveyors, which contained fewer setts. Thus, there were no consistent patterns to suggest that there were differences in the quality of the data within any of the four sub-samples of the data. Therefore, they were pooled for all further analyses.

2.7 *Criteria used for interpreting sett changes*

It was important that any sett changes between the two surveys were correctly identified, and so the surveyor carefully checked the original field data to ensure that they had been recorded correctly. It was possible, for instance, that setts were missed or the position of a sett was wrongly recorded in the original survey. It was emphasized to surveyors to take as much care as possible when making these judgments, especially if they felt that a sett had been missed or if they felt that its status had been wrongly assessed. When making these judgments, information from the relevant landowner, farmer, gamekeeper, shooting tenant or any other person who may know the local badger setts was solicited. Where surveyors felt that the original data had been recorded incorrectly, they were asked to document fully on the recording form their reasons for coming to this decision, providing as much information as possible so that the rationale behind their conclusions could be checked later. These sheets were then carefully evaluated prior to accepting or rejecting the decision of the new surveyor.

The following criteria were used in making these assessments:-

2.7.1 Changes to main setts

On thirty occasions, surveyors considered that a main sett had been missed on the 1980s survey. They usually based this assessment on one or more of the following criteria:-

a. Their personal knowledge of the area extended back to 1980s.

b. The landowner, farmer or gamekeeper knew that the sett was present in the 1980s and from his/her description it appeared to have been a main sett at that time.

c. Evidence of the age of sett, such as a large number of holes, the size of the spoil heaps or the presence of old elder trees at the sett.

d. The difficulty/complexity of the habitat to survey. This occurred when a main sett was found in the 1990s survey in an inaccessible area, such as on a cliff face, or in impenetrable scrub, such that it may have been missed in the 1980s. One main sett had been missed in the 1980s survey because, at the time of the survey, the whole area was flooded, and the surveyor had assumed that there would be no sett under water.

Being sure that a main sett had been missed in the 1980s survey was not easy, and the above criteria are not an infallible guide; it is impossible to be totally sure that a sett was missed. However, based on careful scrutiny of the data, it was concluded it was likely that thirty main setts had been missed in the 1980s survey. These were evenly distributed across the four quality ratings used in the 1980s survey. Of the 2271 1-km squares resurveyed, main setts were thought to have been missed in 11/767 (1·4%), 9/682 (1·3%), 4/202 (2·0%) and 6/620 (1·0%) 1-km squares for quality ratings 1, 2, 3 and 4 respectively. The setts that were judged likely to have been missed were, therefore, evenly distributed across all the quality ratings.

For a further 12 cases (nine from quality rating 2, three from quality rating 4), it was considered likely that a main sett had been missed in the 1980s survey, based on criteria (c) and (d) above, but this was unconfirmed. These setts were considered to have been missed. The original 1980s database was corrected to allow for these 42 main setts for which there was strong evidence, or for which it appeared likely, that they were missed during the 1980s survey. All subsequent changes were measured against these corrected data.

In a very few cases where surveyors considered main setts to have been missed originally, this assessment was not accepted when the previous surveyor was known to be reliable and/or the sett was in an obvious position in terrain that was easy to survey. For these cases, the sett was classified as having been dug between the two surveys.

Where surveyors considered that a main sett had appeared since the 1980s survey, this was accepted by default. Many of these 1-km squares with new main setts were accompanied by reports of a perceived increase in local badger activity, particularly in the last four to five years, as well as substantiating field evidence such as increased levels of badger activity (footprints, paths or runs, or dung pits) and other types of sett in the same 1-km square.

2.7.2 Changes to annexe setts

Where main setts were found in the original survey, it was unlikely that an associated annexe sett would be missed because, by definition, they are close to main setts and usually connected by a clear path. Therefore, where a main sett was recorded in the 1980s survey, any annexe setts that were not recorded then were assumed to have appeared in the intervening years. An annexe setts was considered to have been missed in the 1980s survey when:-

a. It was in association with a main sett which was thought to have been missed in the 1980s survey (n=3).

b. The landowner or some other person confirmed that the annexe sett was definitely present at the time of the 1980s survey. In practice, apart from those annexe setts which were associated with previously missed main setts, this only occurred near to the edge of 1-km squares when there was a main sett outside the 1-km square being surveyed (n=21).

Annexe setts were considered to be new when:-

a. The previous surveyor was known to be reliable and/or the sett was in an obvious position in terrain that was easy to survey. These were generally in association with new main setts; this occurred only rarely.

b. The annexe sett was found near a main sett recorded on the 1980s survey and for which there was no reason to suspect that the annexe sett had been missed.

c. The annexe sett was found in association with a new main sett which was either inside or just outside the 1-km square.

2.7.3 Changes to subsidiary and outlying setts

Subsidiary setts usually consist of only a few holes; mean size in the 1980s was 4.3±0.1 holes, and outlying setts usually consist of only one or two holes; mean size in the 1980s was

1.8±0.1 holes (Cresswell, Harris & Jefferies, 1990). Furthermore, neither type of sett is in continuous use, and so deciding whether such setts had been missed in the 1980s survey was not easy. Therefore, only 20 subsidiary setts and 36 outlying setts were classed as missed when a landowner or some other person confirmed that a sett had been present since before the time of the last survey. All other subsidiary and outlying setts recorded for the first time in the second survey were considered to be new. This obviously invites the possibility of a bias, but the surveying in the original survey was assumed to be of a high standard, so this was considered to be of little importance

2.7.4 Changes in sett status

Any changes in the status of a sett between the two surveys were recorded. This assessment was based on a significant increase or decrease in activity, and whether the sett now appeared to be in one of the other sett categories. Surveyors were asked to provide as much information as possible to enable us to assess the validity of their conclusions. In practise, most of the changes were clear-cut, with setts showing a marked decrease or increase in size and/or activity, leading to a straightforward re-categorisation. In cases where a slight difference in size and/or activity of a sett were noted but it was unclear if it should be placed in a new category, the sett was entered into the database with no change in category.

2.7.5 Setts that had disappeared

The reasons for sett disappearance between the two surveys were recorded where possible. In practise this proved to be difficult to ascertain except where there had been an obvious change in land use e.g. a hedgerow had been removed, or the land built upon. Often, however, the factors leading to the loss of a sett could not be determined with certainty; these setts were, therefore, simply classified as "lost".

2.8 Extracting the data from the field sheets

After the data had been checked and verified, the location of each sett was assigned to one of the following habitat types from the land-use map: hedgerows, treelines, semi-natural broadleaved woodland, broadleaved plantations, semi-natural coniferous woodland, coniferous plantations, semi-natural mixed woodland, mixed plantations, young plantations, parkland, tall scrub, low scrub, bracken, coastal sand-dunes, lowland heaths, heather moorlands, upland unimproved grassland, semi-improved grassland, improved grassland, arable, amenity grassland, unquarried inland cliffs, quarries and open-cast mines, and built land.

Badger activity data were extracted as follows. For each of footprints, paths or runs, and dung pits, the number of the nine sub-squares within each 1-km square that were positive was recorded separately, thus giving a scale of 0 to 9 for each of the three activity measures. Hole blocking, snaring and digging were each scored on a scale of 0 to 3. For hole blocking, "1" denoted only one or two holes blocked, "2" denoted several holes loosely blocked or fewer severely blocked with items such as logs that the badgers would have difficulty in removing, and "3" denoted many holes blocked, often with immovable objects. Snaring was rarely recorded, and then only on the first point of the scale, to indicate some evidence of snaring around the sett; more extensive snaring around setts was not observed, and surveyors were not asked to record snaring away from the sett area. For digging, "1" denoted some evidence of a past attempt at digging into the sett, "2" was a more recent relatively small dig at the sett or a more serious attempt some time ago, and "3" denoted a serious attempt in which several holes had been dug, usually recently. These classifications were based on the field notes supplied by the surveyor (see Appendices 10.1 and 10.2). In practice, the number of setts suffering direct interference, other than hole blocking, proved to be low, and so for digging and snaring these classifications were not subsequently used in the analyses, which were on the presence or absence of each type of interference.

The habitat data were measured to the nearest 0.5 hectares, or the nearest 50 metres for linear features, using a pen tracer and bit pad. In addition to the 40 habitat types listed on the field sheet (Appendix 11.3), two additional habitat types were measured, as had been done in the 1980s surveys. Habitat 41 was sea, which was the area of each 1-km square below the mean low water mark, and habitat 42 was canals, which were separated from canalised ditches (habitat 28) and were recorded as an area and not a linear measure.

Finally, for each 1-km square, the square number, the Ordnance Survey national grid coordinates, the county code and the land class code from the Institute of Terrestrial Ecology's land classification system were recorded, and all the data for each 1-km square were entered in fixed format onto the University of Bristol mainframe computer; 249 columns of data were entered for each 1-km square. The data were then checked manually and by a variety of data checking programmes. In addition, the badger sett changes were entered into a *Microsoft Excel* spreadsheet for each of the 2271 1-km squares. Analyses were carried on SPSS for Unix and Windows, and on dedicated *Excel* spreadsheets.

2.9 Tests for differences between resurveyed and new 1-km squares

A potential bias associated with repeating the same squares in the second survey was the possibility of increased surveyor efficiency in finding setts due to prior knowledge of the square: for each repeat square surveyed in the 1990s survey, each surveyor carried with them the sett details of the original survey with them, in order to record changes to the badger setts (section 2.4).

To check whether this methodology had indeed led to a bias, Mann-Whitney tests were used to compare mean numbers of both main setts, and all other sett types combined, in the 1990s by land class group for the 2271 resurveyed 1-km squares with those in the 307 new 1-km squares (Table 2.3 and Table 2.4). Nationally, there were no differences in either the densities of main or other setts. Main sett densities were higher in both Arable I and Upland VII for new as opposed to resurveyed 1-km squares, but this was almost certainly an artifact of the small number of new 1-km squares surveyed in each of these land class groups. For other sett types, densities were significantly lower in new 1-km squares in Arable II. Whereas the reverse pattern was seen in Upland VII, the sample size was too small for statistical analysis; there were no significant differences for any of the other land class groups. Since there was no evidence that sett densities were higher in 1-km squares surveyed twice compared to those only surveyed once, it was concluded that no bias existed. Hence, the changes recorded during this survey were real rather than artifacts of a biased methodology.

2.10 Data analysis

The sett data were heavily skewed toward zero, particularly for most of the data on badger setts. Therefore use of non-parametric statistical methods was often necessary. Wilcoxon matched pairs tests were used to test for the significance of changes in badger sett numbers between the 1980s and 1990s surveys. Mann-Whitney tests were used to examine differences between samples that were not paired. Kruskal-Wallis tests for differences between three or more groups of samples were used, for example, when testing for differences in the numbers of setts recorded in squares assigned different quality ratings. Rank correlations were used to measure association between two variables on a ranked scale. For example, rank correlations were used to examine the relationship between changes in the number active main setts and disused main setts between the two surveys. Regressions were used to look for a causal relationship between two variables, and to produce models from which predictions could be made, as with the relationship between activity scores and main sett density in Chapter four. Multivariate techniques were employed in Chapter six to explore the relationhips between the various habitat variables an badger distribution.

2.11 Presentation and interpretation of the results

When presenting the results, the percentage change is shown for each land class group or region (where applicable), and the overall percentage change for the sample of 1-km squares that were surveyed. These percentage figures are for the sample squares. It was deemed important that the monitoring scheme was able to detect changes at all population densities. However, because the distribution of badger setts is clumped, with most 1-km squares containing no main setts, population changes within each land class group or each region, in terms of the number of social groups, need to be substantial in areas of very low population density before they can be statistically significant (see Appendix 11.6). These changes are discussed in Chapter three. For those land class groups and regions where the change is not statistically significant because of the underlying nature the data, the survey results still demonstrate real changes in the sample squares for that land class group or region.

Table 2.3 Comparison by land class group of the number of main setts in the 1990s in resurveyed and new 1-km squares. The figures are ± s.e.

Land class group	Number of resurveyed squares	Number of new squares	Mean main sett density, resurveyed squares	Mean main sett density, new squares	Significance of difference
Arable I	208	30	0.45±0.12	0.73±0.14	p<0.05
Arable II	493	76	0.24±0.06	0.18±0.05	n.s
Arable III	188	22	0.10±0.07	0.18±0.11	n.s
Pastoral IV	428	55	0.49±0.10	0.51±0.11	n.s
Pastoral V	333	49	0.25±0.08	0.22±0.07	n.s
Marginal upland VI	335	65	0.14±0.05	0.19±0.05	n.s
Upland VII	286	10	0.02±0.04	0.50±0.31	n.s
Totals	**2271**	**307**	**0.25±0.03**	**0.31±0.03**	**n.s**

Table 2.4 Comparison by land class group of the other of other setts (i.e. annexe, subsidiary, outlying and disused main setts combined) in the 1990sin the resurveyed and the new 1-km squares. The figures are ± s.e.

Land class group	Number of resurveyed squares	Number of new squares	Mean main sett density, resurveyed squares	Mean main sett density, new squares	Significance of difference
Arable I	208	30	2.21±0.77	2.60±0.86	n.s.
Arable II	493	76	0.74±0.22	0.28±0.08	p<0.05
Arable III	188	22	0.22±0.21	0.90±0.66	n.s.
Pastoral IV	428	55	1.94±0.54	1.93±0.45	n.s.
Pastoral V	333	49	0.88±0.31	0.63±0.18	n.s.
Marginal upland VI	335	65	0.62±0.23	0.63±0.18	n.s.
Upland VII	286	10	0.10±0.24	1.30±0.94	-
Totals	**2271**	**307**	0.98±0.15	1.01±0.14	n.s.

Whilst it is likely that the data indicate that there has been a real change overall in that land class group or region, they must be interpreted with caution, particularly where badger densities are low and relatively few 1-km squares contain a main sett.

The two surveys were undertaken over very similar time periods; the first ran from November 1985 until early 1988, the second from October 1994 to January 1997. For each, the majority of the field data were collected in the first two winters, with any gaps in the coverage filled in the early part of the third winter. This is not a completely instantaneous measure of the status of the British badger population. However, completing a large-scale survey in a shorter period of time is impossible. Nor, for logistical reasons, was it possible to ensure that all the squares were resurveyed after exactly the same time period, and so for the great majority of 1-km squares the time between the two surveys was between seven and eleven years. Since the timing of the two visits to any one square were completely independent of any other variable, the time between the two surveys will not cause any bias in the analyses. So for ease of presentation in the report, we treat these samples as if they were exactly nine years apart, and the results are presented as a measure of change for the nine-year period between the ends of the two surveys, i.e. 1988 to 1997.

3. Changes in abundance and distribution of badger setts, 1988 to 1997.

3.1 Introduction

In the repeated badger surveys, main sett presence was interpreted as indication of the presence of a badger social group, therefore main sett distribution was assumed to reflect social group numbers and distribution. This was the parameter of primary interest. In this Chapter the pattern of sett changes in the British badger population between 1988 and 1997 is looked at, with particular attention paid to the changes in the number and distribution of main setts. Factors leading to the loss of main setts are also quantified. I then discuss the changes in the number and distribution of other, smaller sett types, the pattern of change between different categories of sett and, finally, changes in sett size. For these analyses, data from the 2271 1-km squares surveyed in the national surveys in the 1980s and the 1990s are used to compare change. The data are presented both by land class group, and, where appropriate, by region. I have presented the results in this way because the patterns of change were complex; there were clear, smaller-scale regional patterns in addition to changes within the broad landscape types. Viewing the results from both perspectives gives a clearer overall picture of the patterns of change.

3.2 Methods

Data collection, collation, and treatment are described in Chapter two. Sett numbers and sizes for the two surveys are presented for the sample squares, and the precentage change given. The statistical significance is presented. The advantage of a repeat sample design such as this means that any differences observed are real for the sample squares. Despite non-statistically significant differences, in this case due to the clumped underlying distribution of badger setts and associated large confidence intervals, the difference in the sample squares is likely to reflect a trend in the countryside as a whole, because of the fact that badgers setts are relatively intransient and between-square movements of badgers is extremely unlikely (Cochran, 1963).

3.3 Results

3.3.1 Changes in main sett numbers

The changes in the number of main setts recorded in the sample squares are shown in Table 3.1 & Table 3.2. There was an increase overall of 22%. The pattern of change was, however, very variable (Figure 3.1, Figure 3.2 and Figure 3.3). Wilcoxon matched pairs tests showed that of the seven land class groups, the mean number of main setts km^{-2} (i.e. population density in terms of social groups) did not change significantly for Arable I, Arable III, Marginal upland VI and Upland VII (z=-0.34, n.s.; z=-0.24, n.s.; z=-1.83, n.s.; z=-1.60, n.s.; respectively), whereas Arable II, Pastoral IV and Pastoral V all showed significant increases (z=-2.89, p<0.01; z=-3.11, p<0.05; z=-2.92, p<0.01). From a geographical viewpoint, some regions (North England, North-west England, East Midlands, Southern England, South Scotland and South Wales) showed only small changes. The greatest increase was in the West Midlands, where there was a 86% increase in the number of badger social groups. There was significant increase in South-west England (23%). There were also large but statistically nonsignificant increases in the number of badger social groups in the sample squares in North-east England (24%) and Mid and north Wales (35%), and in East Anglia, where there was a rise from 9 to 14 main setts in the 161 1-km squares surveyed.

This latter rise is in close agreement with that recorded in Norfolk by Vine (1993) and in Suffolk by Margaret Grimwade (*pers. comm.*). The fact that the results in the sample squares appear to agree with the findings of other authors working in the same areas, despite the lack of statistical significance, implies that survey protocol detected population changes even in low density areas. The ability of a survey such as this to monitor small badger population changes is discussed in more detail in Appendix 11.6.

The changes in badger density, in terms of social groups km^{-2}, are shown in Table 3.3. There were significant differences in the badger densities across all land class groups (Kruskal-Wallis tests; for the 1980s, X^2=78.5, p<0.0001; for the 1990s, X^2= 103.2, p<0.0001). There were changes in the rank order of the land class groups by main sett density, but those that had similar population densities in the 1980s have remained so (Figure 3.4).

Spearman rank correlations, by land class group, revealed no relationship between main sett density in the 1980s and the percentage change in the number of main setts (r_s=0.23, n.s.), nor the differences in the number of active and disused main setts in the two surveys (r_s=0.77, n.s.). The increases in the number of social groups, therefore, were not determined by the initial 1980s social group densities, nor were the changes simply due to disused main setts being reoccupied.

Table 3.1 The change in the number of badger social groups, 1988-1997, by land class group.

Land class group	Number of squares	Number of main setts in the 1980s	Number of main setts in the 1990s	Percent change	Significance
Arable I	208	95	94	-1	n.s.
Arable II	493	93	117	28	$p<0.01$
Arable III	188	18	17	-6	n.s.
Pastoral IV	428	173	211	22	$p<0.01$
Pastoral V	333	58	84	45	$p<0.01$
Marginal upland VI	335	32	46	44	n.s.
Upland VII	286	2	5	-	n.s.
Totals	**2271**	**471**	**576**	**22**	$\mathbf{p<0.0001}$

Table 3.2 Regional differences in the change in the number of badger social groups, 1988-1997.

Region	Number of squares	Number of main setts in the 1980s	Number of main setts in the 1990s	Percent change	Significance
North England	170	18	19	6	n.s.
North-west England	72	13	12	-8	n.s.
North-east England	121	17	21	24	n.s.
West Midlands	177	44	82	86	$p<0.001$
East Midlands	153	28	29	4	n.s.
Central England	91	22	26	18	n.s.
East Anglia	161	9	14	-	-
South-west England	205	116	143	23	$p<0.01$
Southern England	131	46	49	7	n.s.
South-east England	159	54	62	15	n.s.
North Scotland	366	8	12	-	-
South Scotland	208	15	15	0	n.s.
Mid and north Wales	143	34	46	35	n.s.
South Wales	114	47	46	-2	n.s.
Totals	**2271**	**471**	**576**	**22**	$\mathbf{p<0.0001}$

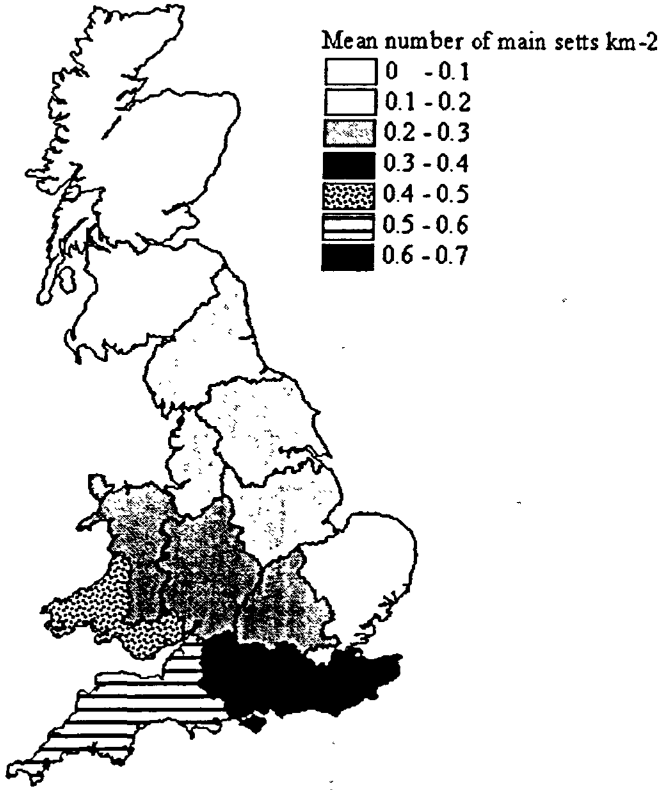


Figure 3.1 Regional variation in the number of main setts km^{-2} in the sample in the 1980s

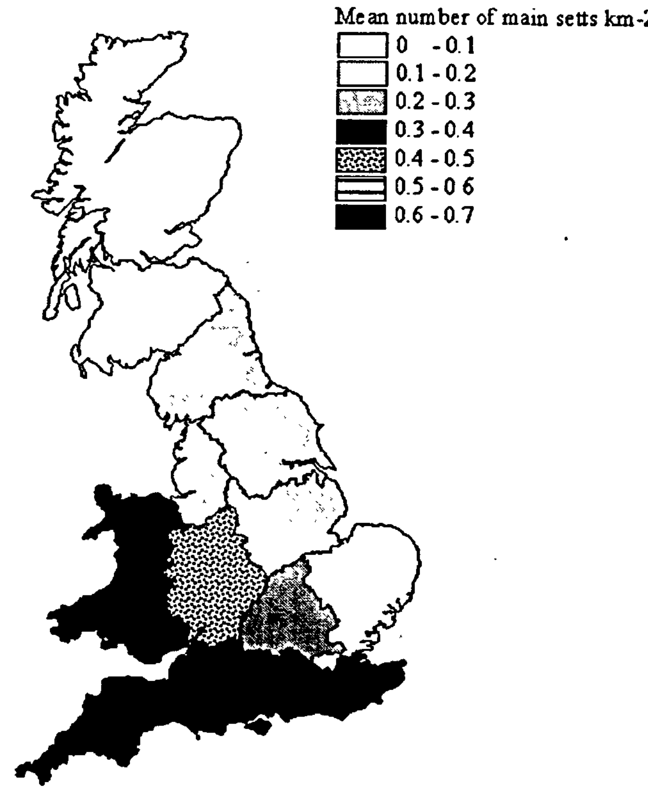


Figure 3.2 Regional variation in the number of main setts km^{-2} in the sample in the 1990s

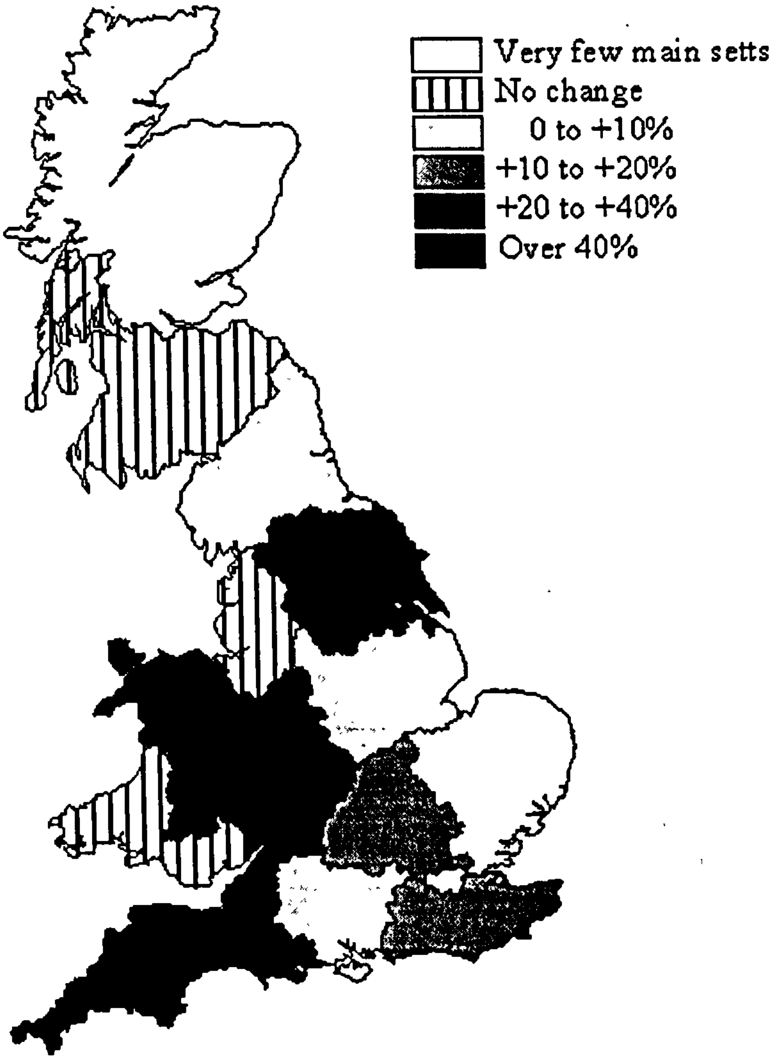


Figure 3.3 Pattern of change in the mean number of main setts km^{-2} in the surveyed squares between the two surveys.

Table 3.3 Changes in the mean number of main setts km-^{2} by land class group between the two surveys.

Land class group	Main sett km^{-2}, 1980s (s.e)	Main sett km^{-2}, 1990s (s.e.)
Arable I	0.457 (0.046)	0.452 (0.050)
Arable II	0.189 (0.023)	0.241 (0.021)
Arable III	0.096 (0.023)	0.090 (0.023)
Pastoral IV	0.404 (0.037)	0.493 (0.037)
Pastoral V	0.174 (0.029)	0.252 (0.025)
Marginal upland VI	0.096 (0.024	0.137 (0.020)
Upland VII	0.007 (0.007)	0.017 (0.005)
Totals	**0.207 (0.008)**	**0.254 (0.007)**

Table 3.4 Losses and gains in the number of main setts, 1988-1997, within each land class group.

Land class group	Number of main setts in the 1980s	Number of main setts "lost"	Number of main setts in the 1990s	Number of new main setts	Percent change overall
Arable I	95	35	94	33	-1
Arable II	93	22	117	48	28
Arable III	18	5	17	5	-6
Pastoral IV	173	45	211	83	22
Pastoral V	58	17	84	43	45
Marginal upland VI	32	12	46	26	44
Upland VII	2	0	5	3	-
Totals	**471**	**136**	**576**	**241**	**22**

3.3.2 Losses of main setts

Although there was a net increase in main setts number overall, there were also substantial losses. Of the 471 main setts recorded in the 1980s, 136 (29%) had been "lost"; this definition includes those setts which were recorded in the 1980s but could no longer be classed as "main" in the 1990s due to a reduction in signs of use. The net increase occurred because the "loss" was compensated for by the addition of 241 main setts in the 1990s (Table 3.4). The losses of main setts since the 1980s occurred across all land class groups, with all showing a quarter to a third of all main setts lost (Table 3.5). For 40 of these (8%), no sign of the sett could be found.

A further 63 (13%) had declined in status; 22 had become disused main setts, 11 annexe setts, 23 subsidiary setts, and seven only had one or two active holes, and were classed as outliers. The remaining 33 main setts had been lost due to known factors (Table 3.6). To determine if there were anything different about the main setts that were lost and those which had persisted from the 1980s to the 1990s, 1-km squares with a single main sett were examined. Squares with only one main sett were used to eliminate any confounding influences from the presence of other main setts nearby. The sample was divided into three groups: those that contained a single main sett in the 1980s but which had no main sett in the 1990s; those with a single main sett in both the 1980s and the 1990s; and those with a single main sett in the 1990s but no main sett in the 1980s (Table 3.7). For these three categories, the size of the main sett (all holes combined) and the number of annexe setts per main sett, were compared. The number of annexe setts per main sett reflects productivity (Cresswell et al., 1992).

1980s

Land class group	Kruskal-Wallis mean rank	Significance
Arable I	1351	
		n.s.
Pastoral IV	1290	
		p<0.0001
Arable II	1132	
		n.s.
Pastoral V	1118	
		p<0.05
Arable III	1047	
		n.s.
Marginal upland VI	1037	
		p<0.0001
Upland VII	951	

1990s

Land class group	Kruskal-Wallis mean rank	Significance
Pastoral IV	1331	
		n.s.
Arable I	1319	
		p<0.0001
Pastoral V	1145	
		n.s.
Arable II	1135	
		p<0.0001
Marginal upland VI	1022	
		n.s.
Arable III	992	
		p<0.0001
Upland VII	921	

Figure 3.4 Comparison of the rank order of the land class groups in terms of social group density, based on mean number of mean number of main setts per km^2. The breaks denote those land class groups where the badger population densities are significantly different.

Table 3.5 Factors leading to the disappearance of main setts recorded in the 1980s, by land class groups.

Land class group	Number of main setts in the 1980s	Number (percent) not found	Number (percent) reduced in status	Number (percent) lost for known reason	Total number of main setts "lost"
Arable I	95	7 (7)	17 (18)	11 (12)	35 (37)
Arable II	93	7 (8)	10 (11)	5 (5)	22 (24)
Arable III	18	2 (11)	2 (11)	1 (6)	5 (28)
Pastoral IV	173	14 (8)	20 (12)	11 (6)	45 (26)
Pastoral V	58	9 (16)	5 (9)	3 (5)	17 (29)
Marginal upland VI	32	1 (3)	9 (28)	2 (6)	12 (37)
Upland VII	2	0	0	0	0
Totals	**471**	**40 (8)**	**63 (13)**	**33 (7)**	**136 (29)**

Table 3.6 Known reasons for the loss of main setts in each land class group

Land class group	Building, development and/or road construction	Digging and/or disturbance	Loss of hedgerow and/or treeline	Loss of woodland	Loss of pasture	Totals
Arable I	1	1	3	4	2	11
Arable II	3	1	-	-	1	5
Arable III	-	1	-	-	-	1
Pastoral IV	-	5	2	2	2	11
Pastoral V	3	-	-	-	-	3
Marginal upland VI	-	-	-	1	1	2
Upland VII	-	-	-	-	-	0
Totals	**7**	**8**	**5**	**7**	**6**	**33**

Table 3.7 Comparison of the main setts that persisted between the two surveys (no change), those that were only present in the 1980s (lost), and main setts that were first recorded in the 1990s (new). For the main setts present in both surveys, data are given for the 1980s and 1990s. The analysis is confined to those 1-km squares that contained a single main sett. The figures are ± s.e.

	Number of 1-km squares	Number of holes per main sett	Mean activity score	Number of annexe setts
Lost main setts	67	9.4±0.7	5.7±0.6	0.30±0.1
No change - in the 1980s	181	13.2±0.8	5.9±0.4	0.34±0.1
No change - in the 1990s	181	15.4±0.8	8.3±0.4	0.68±0.1
New main setts	158	12.0±0.6	8.5±0.4	0.46±0.1

Main setts which had persisted from the 1980s to the 1990s were then compared with new main setts first recorded in the 1990s. The new setts were significantly smaller ($z=-3.31$, $p=0.001$), they had significantly fewer annexe setts ($z=-2.17$, $p<0.05$), but the squares in which they were contained had similar activity scores to the previously occupied squares ($z=-0.49$, n.s.). Thus, even though there are comparable levels of badger activity as recorded by field signs, new main setts are smaller. When comparing the main setts recorded in the 1980s that had disappeared by the 1990s, with those which had persisted between the surveys, there was no significant difference in the total activity scores ($z=-0.002$, n.s.) or the annexe to main sett ratio ($z=-0.30$, n.s.), but the main setts that were lost were significantly smaller ($z=-2.60$, $p<0.01$).

3.3.3 Changes in the number of other types of sett

The pattern of change in other types of sett is summarised in Appendix 11.7. The most substantial increase was for annexe setts, which in the surveyed squares increased by 82% in the sample squares; subsidiary and outlying setts increased by 53% and 51% respectively. The number of disused main setts declined by 42%. In the 1980s, the average number of setts per social group was 4.10 (one main, 0.24 disused main, 0.43 annexe, 0.86 subsidiary and 1.57 outlying setts). By the 1990s, this had risen to 4.96 (one main, 0.11 disused main, 0.69 annexe, 1.14 subsidiary and 2.02 outlying setts).The disproportionate increase in number of annexe setts was the most striking result. The ratio of annexe to main setts in the 1980s and 1990s is illustrated in Figure 3.5 by land class group and in Figure 3.6 by region.

Wilcoxon matched pairs tests showed that of the seven land class groups, the mean number of annexe, subsidiary and outlying setts combined km^{-2}, did not change significantly for Arable III and Upland VII ($z=-0.68$, n.s.; $z=-1.36$, n.s.; respectively), whereas Arable I, Arable II, Pastoral IV, Pastoral V and Marginal upland VI all showed significant increases ($z=-4.19$, $p<0.0001$; $z=-3.79$, $p<0.001$; $z=-6.51$, $p<0.0001$; $z=-2.98$, $p<0.01$; $z=-3.26$, $p<0.001$). Some regions (e.g. North-west England, Southern England and South Scotland) that showed little or no growth in the number of social groups still showed substantial growth in the number of annexe and other sett types within established social groups. Other regions that showed little growth in the number of social groups (e.g. North England and East Midlands) also showed little increase in the number of annexe setts within established social groups. Conversely, land class groups (e.g. Arable II) and regions (e.g. North-east England and East Anglia) that showed a substantial growth in the number of social groups showed little increase in the number of annexe or other sett types within social groups. There was no relationship ($r_s=0.03$, n.s.) between percent change in the number of main setts and percent change in number of annexe setts, by land class group.

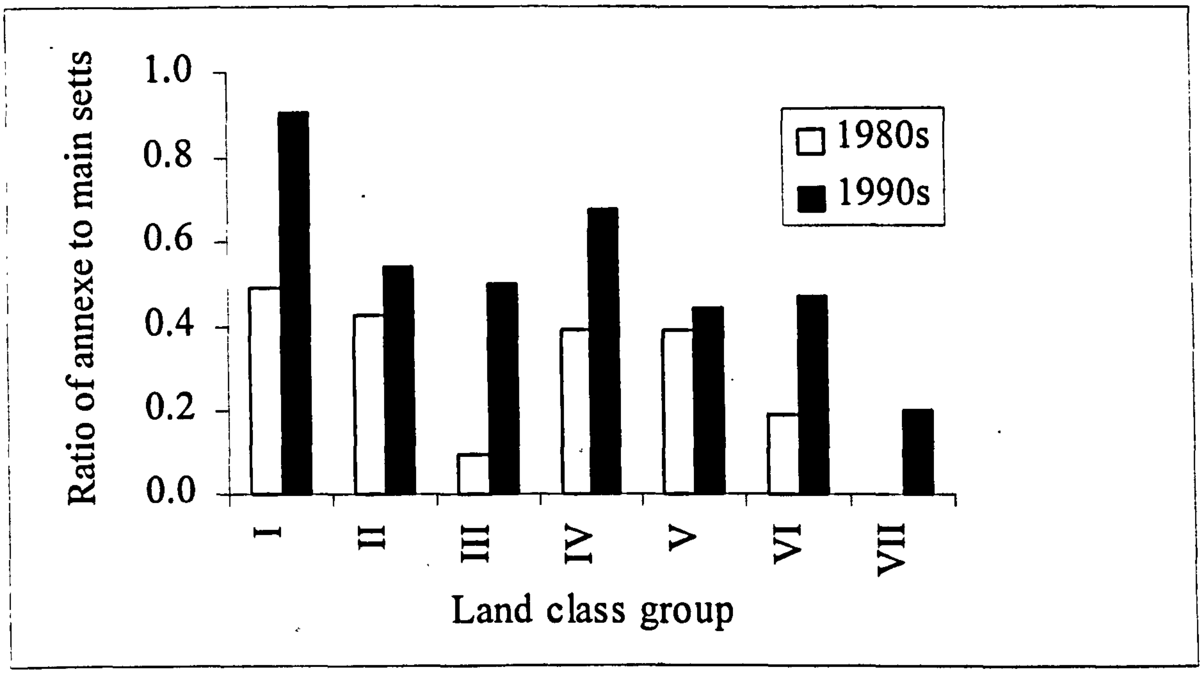


Figure 3.5 Changes in the ratio of annexe to main setts by land class group

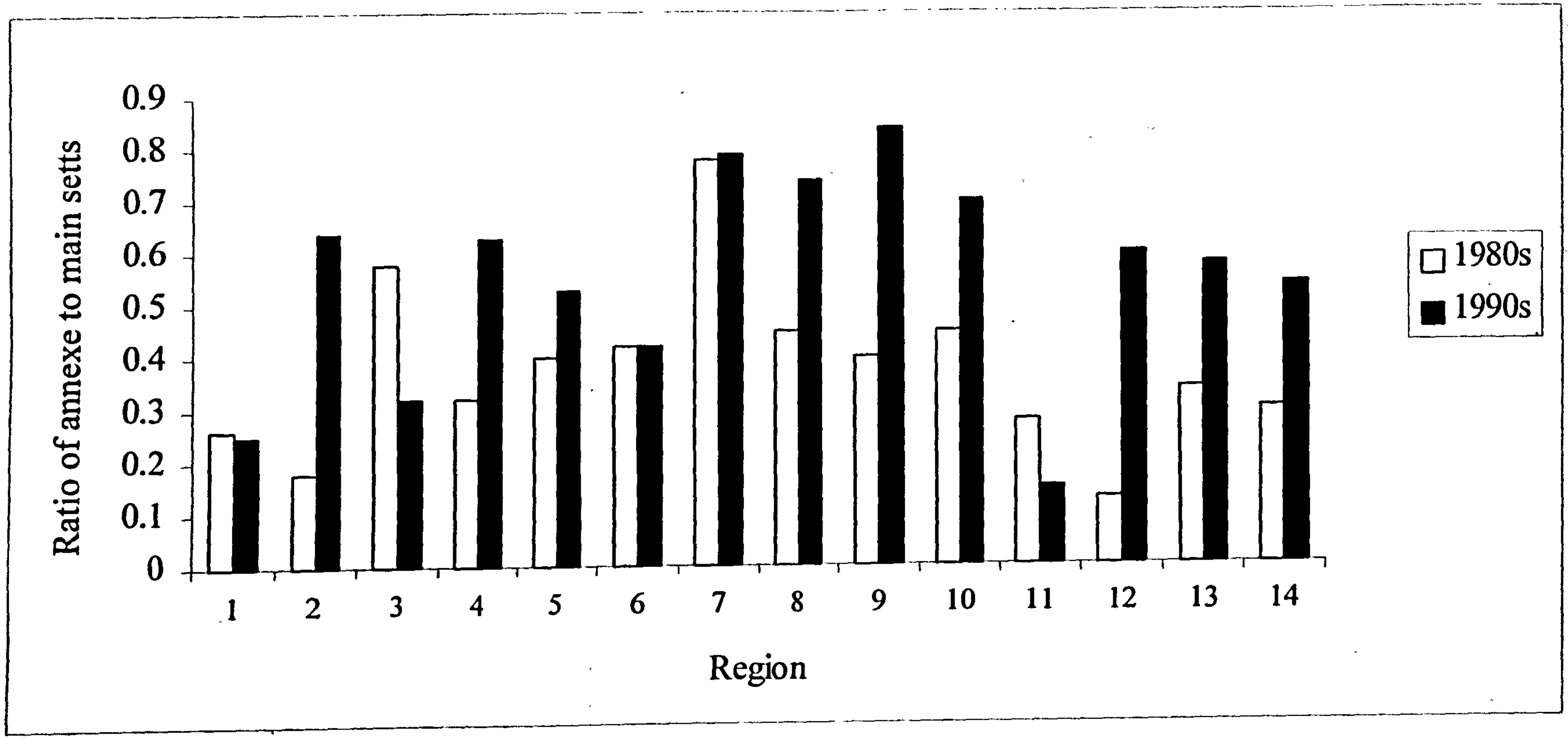


Figure 3.6 Regional pattern of changes in the ratio of annexe to main setts. The numbers denote the regions as follows: 1=North England, 2=North-west England, 3=North-east England, 4=West Midlands, 5=East Midlands, 6=Central England, 7=East Anglia, 8=South-west England, 9=Southern England, 10=South-east England, 11=South Scotland, 12=North Scotland, 13=Mid and north Wales, 14=South Wales. The counties included in each region are listed in section 2.2.

3.3.4 Changes in the status of setts

For the smaller sett types that disappeared or fell into disuse, it was difficult to determine the exact reasons for their disappearance because few field signs remained. However, some smaller sett types increased in status, and became main setts; these changes are summarised in Table 3.8. Losses of disused main setts are shown in Table 3.9; of the 64 disused main setts recorded in the 1990s, 22 (34%) had been active main setts in the 1980s.

Table 3.8 Summary of the types of sett that changed in status between the two surveys to become active main setts

Land class group	Annexe setts	Subsidiary setts	Outlying setts	Disused main setts
Arable I	0	6	0	0
Arable II	4	3	4	2
Arable III	0	0	0	2
Pastoral IV	6	10	7	6
Pastoral V	0	6	4	4
Marginal upland VI	0	3	2	2
Upland VII	0	0	0	0
Totals	**10**	**28**	**17**	**16**
Number in the 1980s	220	429	769	111
Percent changed	5	7	2	14

Only 70/241 (29%) of the new main setts originated by expansion of an established, lower status sett. The category of sett which most regularly expanded to become a main sett was subsidiary; 28 (7%) of these became main setts between the two surveys. Of the 14 annexe setts that became main setts, in five cases there was a simple exchange of status with the nearby main sett. Most new main setts were dug from new, reinforcing the assertion that the different sett types are functionally different and are established in different types of locality. Thus a site that may be suitable for an outlying sett, for instance, may not be suitable for a main sett.

Table 3.9 Changes in the status of disused main setts recorded in the 1980s

Land class group	Sett was still a disused main sett	Sett could not be found	Sett only used by rabbits	Sett had become an active main sett	Sett had become an annexe sett	Sett had become a subsidiary sett	Sett had become an outlier sett	Totals
Arable I	10	6	1	0	0	4	0	21
Arable II	8	6	1	2	1	2	1	21
Arable III	0	1	1	2	0	0	0	4
Pastoral IV	6	7	2	6	1	1	0	23
Pastoral V	8	10	4	4	0	3	3	32
Marginal upland VI	3	3	0	2	0	0	0	8
Upland VII	0	2	0	0	0	0	0	2
Totals	**35**	**35**	**9**	**16**	**2**	**10**	**4**	**111**

3.3.5 Changes in the distribution of badger setts

In parallel with a significant increase in the number of main setts, there was also an increase in the distribution of badgers. Most of the increase of numbers of main setts was in the form of 1-km squares which contained no main setts in the 1980s gaining one by the time of the 1990s survey. Despite this, the majority of 1-km squares surveyed still did not contain a badger sett in the 1990s. The distribution of 1-km squares with main setts in the two surveys is shown by land class groups and regions in Table 3.10 & Table 3.11, and all types of sett by land class groups and regions in Table 3.12 & Table 3.13. In the 1980s, only 378/2271 1-km squares (17%) contained main setts, and 676/2271 1-km squares (30%) contained setts of any type. Taking just the five lowland land class groups, which excludes the very low density upland areas of Scotland, only 21% contained main setts in the 1980s, and 33% setts of any type. Main setts were found in an additional 4%, and any setts in an additional 3%, of all rural 1-km squares in the 1990s. For the five lowland land class groups, these figures are also 4% and 3% respectively.

Table 3.10 Changes in the number of 1-km squares in each land class group containing main setts in the two surveys.

Land class group	Number of squares	Number (percent) of 1-km squares with main setts in the 1980s	Number (percent) of 1-km squares with main setts in the 1990s	Percent change	Significance
Arable I	208	74 (36)	76 (37)	3	n.s
Arable II	493	81 (16)	102 (21)	26	n.s
Arable III	188	17 (9)	15 (8)	-12	n.s
Pastoral IV	428	126 (29)	160 (37)	27	$p<0.01$
Pastoral V	333	51 (15)	72 (22)	41	n.s
Marginal upland VI	335	27 (8)	37 (11)	37	n.s
Upland VII	286	2 (1)	5 (2)	-	-
Totals	**2271**	**378 (17)**	**467 (21)**	**24**	**$p<0.0001$**

Table 3.11 Regional changes in the number of 1-km squares with main setts, 1988-1997.

Region	Number of squares	Number (percent) 1-km squares with main setts in the 1980s	Number (percent) 1-km squares with main setts in the 1990s	Percent change	Significance
North England	170	17 (10)	18 (11)	6	n.s.
North-west England	72	11 (15)	11 (15)	0	n.s.
North-east England	121	12 (10)	17 (14)	42	n.s.
West Midlands	177	42 (24)	68 (38)	59	$p<0.001$
East Midlands	153	26 (17)	27 (18)	4	n.s.
Central England	91	19 (21)	24 (26)	26	n.s.
East Anglia	161	9 (6)	14 (9)	56	-
South-west England	205	78 (38)	105 (51)	35	$p<0.001$
Southern England	131	36 (27)	42 (32)	17	n.s.
South-east England	159	46 (29)	46 (29)	0	n.s.
North Scotland	366	6 (2)	10 (3)	67	-
South Scotland	208	15 (7)	14 (7)	-7	n.s.
Mid and north Wales	143	28 (20)	34 (24)	21	n.s.
South Wales	114	33 (29)	37 (32)	12	n.s.
Totals	**2271**	**378 (17)**	**467 (21)**	**24**	$\mathbf{p<0.0001}$

Table 3.12 Changes in the number of 1-km squares in each land class group containing any setts (i.e. all types combined) in the two surveys.

Land class group	Number of squares	Number (percent) of 1-km squares with main setts in the 1980s	Number (percent) of 1-km squares with main setts in the 1980s	Percent change	Significance
Arable I	208	115 (55)	117 (56)	2	n.s.
Arable II	493	140 (28)	160 (32)	14	p=0.01
Arable III	188	31 (16)	28 (15)	-10	n.s.
Pastoral IV	428	209 (49)	229 (54)	10	$p<0.05$
Pastoral V	333	111 (33)	125 (38)	13	p=0.01
Marginal upland VI	335	60 (18)	74 (22)	23	n.s.
Upland VII	286	10 (3)	13 (5)	30	n.s.
Totals	**2271**	**676 (30)**	**746 (33)**	**13**	$\boldsymbol{p<0.0001}$

Table 3.13 Regional changes in the number of 1-km squares with setts (i.e. all types combined), 1988-1997.

Region	Number of squares	Number (percent) 1-km squares with setts in the 1980s	Number (percent) 1-km squares with setts in the 1990s	Percent change	Significance
North England	170	44 (26)	41 (24)	-7	n.s.
North-west England	72	22 (31)	25 (35)	14	n.s.
North-east England	121	24 (30)	23 (19)	-4	n.s.
West Midlands	177	84 (47)	115 (65)	37	$p<0{\cdot}0001$
East Midlands	153	42 (27)	50 (33)	19	n.s.
Central England	91	35 (38)	35 (38)	0	n.s.
East Anglia	161	18 (11)	27 (17)	50	$p=0{\cdot}05$
South-west England	205	130 (63)	145 (71)	12	$p<0{\cdot}05$
Southern England	131	58 (44)	64 (49)	10	n.s.
South-east England	159	68 (43)	68 (43)	0	n.s.
North Scotland	366	24 (7)	20 (5)	-17	n.s.
South Scotland	208	41 (15)	25 (12)	-19	n.s.
Mid and north Wales	143	35 (31)	55 (38)	22	n.s.
South Wales	114	51 (45)	53 (46)	4	n.s.
Totals	**2271**	**676 (30)**	**746 (33)**	**13**	$\boldsymbol{p<0.0001}$

3.3.6 Changes in the size of setts

Changes in the size of main setts are shown in Table 3.14 by land class group, and by region in Appendix Table 11.8.1. Annexe, subsidiary and outlying setts are also summarised by land class group and regions in Appendix 11.8. Overall, there were significant increases in the size of main setts since the 1980s, a small increase in the size of subsidiary setts, but no change in the size of annexe and outlying setts. For main setts, the majority of the increase in size occurred due to an increase in the number of well-used holes; there was a small decrease in the number of disused holes. For annexe setts, there was an increase in the ratio of well-used to disused holes, but no overall increase in hole number. For subsidiary setts, the increase in size was the result of an increase in the number of well-used holes. There was no change for outlying setts.

The regional patterns of change are more complex; regions such as North England and North-west England, which showed little or no increase in the number of social groups, showed substantial growths in the sizes of main setts, whereas regions such as North-east England and the West Midlands, which showed significant increases in the number of badger social groups, showed little growth in the size of main setts. The pattern of change for the smaller types of sett was even more variable.

Table 3.14 The change in the size of main sett, 1988-1997, by land class group; figures are ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Land class group	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1980s	Number of disused holes in the 1980s	Number of disused holes in the 1980s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
Arable I	6.1±0.4	8.4±0.7	3.0±0.3	4.5±0.6	3.1±0.5	3.7±0.5	12.5±0.8	16.6±1.5	$p<0.001$
Arable II	5.8±0.5	8.7±0.7	3.4±0.4	3.4±0.4	4.1±0.7	3.2±0.4	13.5±1.0	15.2±1.1	$p=0.0001$
Arable III	4.4±0.8	5.3±1.1	1.8±0.5	2.1±0.4	1.4±0.6	1.6±0.4	7.6±1.3	9.1±1.2	*n.s.*
Pastoral IV	6.5±0.5	8.4±0.5	3.5±0.4	3.9±0.3	3.2±0.4	3.2±0.3	13.3±1.0	15.5±0.8	$p<0.0001$
Pastoral V	5.5±0.9	8.0±0.6	2.0±0.3	3.0±0.4	2.3±0.6	2.0±0.3	9.8±1.2	12.9±1.0	$p<0.001$
Marginal upland VI	4.5±0.8	7.7±0.7	1.8±0.4	2.6±0.5	2.8±1.1	1.3±0.4	9.4±1.6	11.5±1.1	n.s.
Upland VII	3.5±0.5	5.0±0.6	1.9±1.0	3.4±1.6	2.5±2.5	1.0±0.6	7.0±1.0	9.4±2.1	n.s.
Totals	**5.9±0.5**	**8.2±0.3**	**2.9±0.2**	**3.6±0.2**	**3.1±0.3**	**2.9±0.2**	**12.3±0.5**	**14.6±0.5**	$\mathbf{p<0.0001}$

3.3.7 The number of badger social groups in Britain

The total number of badger social groups in Britain was estimated, using the mean main sett densities for each land class group adjusted for area of sea in the sample squares (Table 3.14). These density estimates are based on the number of 1-km squares that were surveyed, minus the area of sea. Only 1-km squares that were predominantly rural were included in the survey. The number of urban squares in each land class comes from the Countryside Information System (version 5.40) (Institute of Terrestrial Ecology, Monks Wood, Abbots Ripton, Huntingdon, PE17 2LS). For this, urban 1-km squares were defined as being more than 75% built up. The densities for each land class group were then multiplied by the number of rural 1-km squares to give the number of badger social groups; the 95% confidence intervals were calculated as explained in Appendix 11.6. By this means the number of badger social groups in Britain was estimated as 50,241±4327.

Table 3.14 The number of badger social groups in Britain in the 1990s.

Land class group	Number of 1-km squares in land class group	Area (km^2) of rural land in land class group	Mean main sett density in the 1980s	Mean main sett density in the 1990s	Total number of main setts
Arable I	14460	14069	0.457	0.452	6366
Arable II	48385	46387	0.189	0.241	11381
Arable III	18339	17391	0.096	0.090	1600
Pastoral IV	34730	30949	0.404	0.493	16743
Pastoral V	35383	33974	0.174	0.252	8586
Marginal upland VI	35483	34793	0.096	0.137	4816
Upland VII	45150	42069	0.007	0.017	749
Totals	**231885**	**219633**	**0.207**	**0.254**	**50241**

Table 3.15 The number of badger setts in Britain. The percent change is the change in the total number of setts in Britain between the two surveys.

Land class group	Number of active main setts	Number of annexe setts	Number of subsidiary setts	Number of outlier setts	Number of disused main setts	Totals
Arable I	6366	6197	10,422	14,647	986	38,618
Arable II	11,381	7084	9455	18,889	1417	48,216
Arable III	1600	711	1244	1777	178	5510
Pastoral IV	16743	12,566	19,019	33,962	1698	83,988
Pastoral V	8586	4089	9199	16,354	681	38,909
Marginal upland VI	4816	3164	5237	13,911	703	27,667
Upland VII	749	132	1762	2202	132	4977
Totals	**50,241**	**33,942**	**56,364**	**101,543**	**5795**	**247,885**
Percent change since the 1980s	24	87	54	55	-41	43

In the 1980s, only a small sample of 1-km squares in Britain had been classified to a land class (section 2.2), and estimates of the area of each land class in Britain were less precise than those available today. Thus, Cresswell, Harris & Jefferies (1990) used 207,501 km^2 as the estimate of the area of rural land in Britain when deriving their population estimate, whereas in this survey an estimate of 219,633 km^2 was used. Mainly as a result of the improved estimate for the area of rural land in each land class, it is estimated that the number of badger social groups in Britain has risen by 24%, despite the new estimate for the number of badger social groups in Britain is not being exactly 24% higher than that presented in the original survey report (Reason, Harris & Cresswell, 1993). Since this is a rural survey, this estimate does not include the number of badger social groups living in urban areas. In the 1980s, Cresswell, Harris & Jefferies (1990) estimated that there were no more than 200 active main setts in urban areas, and of these 37 were in Bristol, the city with the largest urban badger population (Harris & Cresswell, 1991). Since then, a number of local Badger Protection Groups have reported an increase in the number of badgers seen in urban areas (E. King, *pers. comm.*). Badgers in urban areas are still likely to constitute only a very small proportion of the total population.

The same approach was used to estimate the number of setts of all types in each land class group and Britain as a whole (Table 3.15). The percentage change in the actual number of setts since the 1980s in Britain is also shown; there are now estimated to be 247,885 setts of all types in Britain - 70,000 more than the estimate of Cresswell, Harris & Jefferies (1990). This table also shows the percent change in the number of each type of sett for Britain as a whole.

3.4 Discussion

3.4.1 Changes in numbers and distribution of setts.

In this Chapter, it has been shown that between the 1980s and 1990s surveys, there was a 24% increase in the number of badger social groups, and that this pattern of increase was not evenly distributed across Britain. The original density of main setts in the 1980s did not appear to determine the level of change in sett numbers within the land class groups. Regionally, the changes were complex, with some regions showing little or no increase in the number of badger social groups, but others showing substantial increases. The loss or decline of 29% of all main setts in a decade was surprising, given that it has been argued that main setts are a valuable resource that are not easily replaced (Doncaster & Woodroffe, 1993; Roper, 1993). Of the main setts recorded in the 1980s, 33 (7%) had been lost as a consequence of land use changes. How many of these were destroyed illegally, and how many legally i.e. a licence had been issued under the Protection of Badgers Act 1992, was not known. In some cases the loss of the main sett may have been accidental e.g. some main setts were covered by fallen trees in the gale of 16 October 1987, and subsequently destroyed by the heavy machinery that cleared the fallen trees (Stephen Harris, *pers. comm.*). This may have contributed to the loss of the seven main setts where the causal factor was identified as being woodland loss.

For the 8% of main setts which could no longer be found, in the absence of any obvious reasons, it was difficult to determine the causal nature of their loss. This was due to the "snapshot" nature of the surveys. Failure to find any sign remaining of badger main setts suggests that they had fallen into disuse some considerable time before, since evidence of disused badger setts can persist for some time (Neal & Cheeseman, 1996). Badger social groups are known to be very variable in terms of the disturbance levels they will tolerate before deserting a main sett. It has been recorded (Roper, 1993) that badgers will sometimes endure intense disturbance to remain in the natal main sett. They also commonly dig their setts into busy road and rail embankments. Badgers in urban areas appear to be habituated to everyday human noises. Yet on the other hand, it has been noted that a group will relocate for apparently innocuous reasons. Badger groups living in setts in pasture have been observed to desert the sett when cattle were introduced, and conversely when cattle were removed, thus reducing the feeding potential of favoured foraging sites (J. Brown, *pers. comm.*). So despite the reputed importance of main setts as a resource to badgers, there is clearly a proportion of the population which will desert their natal main sett, for reasons as yet unclear. Of the known factors leading to main sett loss, digging and human disturbance were the most common. This could be an important factor in terms of main sett declines. Digging is one of the only types of direct human impact that can recorded by this survey methodology. It is by no means the only form of persecution (Chapter seven) with the traditional pest control operations of shooting, gassing and snaring each having at least as great an impact. Therefore I suggest that human persecution is an important parameter determining the loss and decline of badger main setts. It can also be argued that more recent colonists are affected most by these factors, since the main setts which were "lost" were significantly smaller than those that persisted. Total sett size in terms of number of entrance holes is known to be a correlate of age (Kruuk, 1978; Neal & Roper, 1993) suggesting that on average those setts which did not persist were 'younger'. This could be interpreted in terms of intolerance of a proportion of the landowners or farmers to the establishment a badger population on their land. Further evidence for the continuing role of persecution in the population patterns of badgers in Britain is discussed in Chapter seven.

3.4.2 Changes in group size

The impressive increases in numbers of smaller sett types, and size of setts (particularly at main setts and in terms of active holes) provide strong evidence to suggest that group sizes have increased on average, in addition to the number of groups. The increase in the number of annexe setts was of particular importance. Cresswell *et al.* (1992) showed that annexe setts serve as additional breeding sites and correlate with increased productivity within social groups. They also tend to indicate larger social groups. Thus the growth in the number of other types of sett, and particularly annexe setts, is a measure of growth within badger social groups. The relative contributions of increasing group size and numbers of groups to the overall population change is investigated in Chapter four. The relationships between the number, size and activity of setts, and social group are explored in Chapter five.

These data taken together show that the patterns of change in the badger population have been complex; increases in the number of social groups are not necessarily matched by growth within social groups, but there can be growth within social groups without population expansion into new areas. Reasons for these observations are likely to be manifold, and influenced by a number of factors; initial badger density; availability of suitable main sett sites; availability of suitable outlying sett sites; historical and current patterns of land-use and persecution.

3.4.3 Changes in the distribution of badger social groups

The absence of any type of badger sett from the majority of lowland rural Britain despite the considerable increase in numbers suggests either that substantial areas of rural Britain were unsuitable for badgers, or else historical anthropogenic factors have led to the loss of badgers from much of rural Britain. Equally, their recent spread into new areas suggests that the factors limiting their distribution hitherto have changed. Again human activities, both land-use and persecution are likely to be important factors.

3.5 Summary

Badger social groups were estimated to have increased in number by 24% between the original baseline survey and the repeat whose findings are documented here. In 1997 there were estimated to be 50,241±4327 badger social groups in rural Britain. This change was not uniform across the country, being least in two of the three arable land class groups. Regionally, there was also great variation in the patterns of change; some regions showed very large increases while in others there was little change or even small declines. Smaller sett categories increased to an even greater extent; annexe setts increased by 87%, subsidiary setts by 54%, and outliers by 55%. The number of disused setts declined by 41%. There was a surprising amount of 'churning' of sett numbers. 29% of all main setts recorded in the original survey had either been lost of declined in use and status. Main setts increased in size in terms number of entrance holes, and in particular, active entrance holes. Combined with the large increase in other sett categories, this was interpreted as evidence of increases in social group size in addition to an increase in number of social groups. The patterns of change in these factors were also complex; in some regions there had been increases in number of social groups, but no change in the size of main setts, while in others there had been no change in social group numbers, but significant increases in sett size and numbers of smaller setts. In conclusion, there has been an overall trend in Britain for an increase in badger numbers, but the patterns of change have been complicated.

Chapter four investigates the changes in badger numbers (the product of group size increase and increasing numbers of groups) using the field sign index developed for the survey.

4. Badger population changes, 1988 to 1997: estimated change in relative abundance

4.1 Introduction

In Chapter three, it was recorded that there had been a 24% increase in the number of badger social groups throughout Britain, in the nine years between the two national surveys. It was also found that there had been a disproportionally large increase in the number of smaller sett types, and that the size of main setts had increased on average. This suggested that there had been an increase in average social group size across much of the country. The actual change in badger numbers, therefore, would be product of these two modes of change. In this Chapter, a field sign index is used to estimate the relative increase in actual badger numbers between the two surveys.

Other than at very low population densities, badgers mark their territorial boundaries, and features within the territory, with latrines (Neal & Cheeseman, 1996). In addition, there are often conspicuous pathways connecting the boundary latrines, and well-used pathways within the territory connecting setts and leading to foraging areas. These are often particularly obvious where they pass through a hedge or under a fence. Finally, badgers leave characteristic foraging signs, as described by Neal & Cheeseman (1996). These field signs are easy to find and distinguish from those left by other species. Field signs, and particularly faeces, are frequently used as a measure of animal abundance e.g. see reviews by Putman (1984), Staines & Ratcliffe (1987) and Sutherland (1996). Factors such as the dunging behaviour of the particular species being studied, differential search ability of surveyors, differential ease with which signs can be found in different habitat types, and differential decay rates, amongst others, can all in theory affect the reliability of dung counts for estimating the abundance of animals. However, Putman (1984) concluded that, when trying to use field signs to assess abundance, there is good evidence to conclude that many of the potential sources of error are insignificant in practice. This is likely to be particularly true with badgers: their faeces accumulate in latrines (Brown, 1993) which are easy to identify and persist for extended periods. Finding dung pits is also made easier because badgers generally place their latrines in conspicuous places (Kruuk, 1978). Also, other field signs, such as paths and runs were recorded which are obvious irrespective of weather conditions.

The idea that counts of dung pits or latrines, or other field signs, may provide a measure of the number of badgers in an area is supported by the work of Brown (1993) and Hutchings (1996). Brown (1993) showed that the number of faeces produced each night is constant each season, and so the number of faeces deposited in a territory in a particular time period can be used as a measure of social group size (Brown, 1993; Hutchings, 1996). Factors such as variable weather conditions, which affects breakdown rates of faeces, and seasonality of dunging behaviour have to be taken into account when proceeding with such work.

Faecal density *per se* is not easy to measure in the field. However, changes in the levels of incidence of badger field signs can be measured with confidence if the measures used are easily quantified in the field and can be recorded equally reliably across all habitat types. Both the 1980s and the 1990s, surveys were undertaken across exactly the same months of the year, and the same squares were repeated. Also, by taking large samples from each land class group, average activity levels could be calculated for each grouping, in each survey and compared. This large scale approach means that approximate comparisons can be made with confidence. The timing of the field work was advantageous, being confined to the autumn, winter and early spring, when vegetation is lowest and field signs were most visible. Finally, many of the field signs that were recorded (dung pits, rather than actual faeces, paths and runs) remain visible for an extended period, irrespective of how recently they had been used. Thus seasonal variability in the behaviour of badgers will be less important when monitoring a variety of field signs than if a single measure, such as faecal counts, was used.

In this Chapter, a simple index of field sign incidence is used to estimate changes in the relative abundance of badgers from the 1980s to the 1990s. The results complement those in Chapter three, which highlighted primarily the changes in abundance and distribution of social groups. The analysis is extended to estimate how much of the change has been due to the growth in social group size, and how much has been due to the spread of badgers and the establishment of new social groups. The limitations of the data and assumptions used are discussed, as is the further work that is required.

4.2 Methods

4.2.1 Data collection

Data on social groups were recorded and collated as described in Chapter two. During both surveys, the presence or absence of footprints, paths or runs, and dung pits were recorded in a nine sub-square grid within the 1-km square. The relative proportion of 1-km squares with the various field signs recorded remained the same between the two surveys (Table 4.1), indicating that the incidence of these measures was consistent, and their likelihood of discovery by surveyors was not unduly influenced by any extrinsic circumstances, such as weather conditions, between the two surveys. Furthermore, paths or runs were the field signs recorded most frequently, and these were the field signs that were particularly obvious and were least likely to be influenced by weather conditions.

Table 4.1 Changes in the number (percent) of field signs in the two surveys

	Number (percent) of 1-km squares with signs in the 1980s		Number (percent) of 1-km squares with signs in the 1990s	
Footprints	380	(17)	601	(28)
Paths or runs	666	(29)	810	(36)
Dung pits	397	(17)	643	(26)

From these field data, measures of "activity score" for each square were obtained by combining all these scores (score range 0 to 27), and measures of scent marking activity by combining the scores for "dung pit score" (score range 0 to 9).

4.2.2 Data analysis

The relationships between badger setts and field signs were explored in order to estimate the proportional change in badger numbers in the period between the two surveys. In this section, looking at the estimated change in badger numbers, the value for badger social group density was converted to actual badger density by multiplying by a global average group size figure of 5.9 adult badgers per group. This was considered to be the case at the time of the 1980s survey (Cresswell, Harris & Jeffries, 1990). However, that figure was produced from a review of a relatively small number of studies into badgers, primarily in high-density habitats. Since then, further research has revealed the extent of the variability in social group size, and that the figure of 5.9 badgers/group is likely to be too high for many areas of the country. It must be stressed, therefore, that figures presented for overall number of badgers are hypothetical: altering this global mean value changes the numbers of badgers in the 1980s, the relationship between field sign index and badger numbers, and therefore the resultant estimate of badger numbers in the 1990s. However, changing this value does not affect the estimate of proportional change in badger numbers between the two surveys. The effect of the variation in group size on the estimates of change in badger numbers is explored in Chapter five.

4.3 Results

4.3.1 Changes in incidence of field signs

In the 1990s, a higher incidence of field signs was recorded than in the 1980s in each land class group. For the sample as a whole, dung pit scores increased by 92%, and activity scores increased by 69%. There was a significant (Wilcoxon) increase in both these measures in every land class group except upland land class group VII (Table 4.2, Table 4.3). Upland VII is exceptional in that, as mentioned in Chapter three, it is montane and supports very low numbers of badgers and, therefore, field signs. Any small change in numbers of setts or incidence of signs in even one square results in a large percentage change. The contribution to the overall badger population in Britain from land class group VII, is extremely small and is discounted in some of the following analyses. Distribution of signs was greater in the 1990s. When comparing the number of squares in the two surveys with any signs of activity, there was a significant increase in both measures. Squares ontaining dung pits increased from 17% to 22%. Squares with presence of any activity increased from 31% to 38%.

Table 4.2 Changes in activity score between the two surveys, by land class group.

Land class group	Number of squares surveyed	Mean activity score ± s.e.in the 1980s	Mean activity score ± s.e.in the 1990s	Percent change	Significance
Arable I	208	3.86±0.37	4.66±0.37	21	p<0.01
Arable II	493	1.57±0.16	2.94±0.16	87	p<0.0001
Arable III	188	0.52±0.10	0.94±0.19	81	p<0.05
Pastoral IV	428	3.07±0.22	5.34±0.32	74	p<0.0001
Pastoral V	333	1.59±0.19	3.03±0.31	91	p<0.0001
Marginal upland VI	335	0.79±0.12	1.71±0.24	117	p<0.0001
Upland VII	286	0.25±0.09	0.26±0.11	4	n.s.
Totals	**2271**	**1.70±0.08**	**2.88±0.11**	**69**	**p<0.0001**

Table 4.3 Changes in dung pit score between the two surveys, by land class group.

Land class group	Number of squares surveyed	Mean dung pit score ± s.e.in the 1980s	Mean dung pit score ± s.e.in the 1990s	Percent change	Significance
Arable I	208	0.96±0.12	1.22±0.13	27	p<0.05
Arable II	493	0.35±0.05	0.72±0.07	106	p<0.0001
Arable III	188	0.12±0.03	0.27±0.07	132	p<0.05
Pastoral IV	428	0.61±0.06	1.24±0.09	103	p<0.0001
Pastoral V	333	0.33±0.05	0.77±0.08	133	p<0.0001
Marginal upland VI	335	0.18±0.04	0.48±0.07	167	p<0.0001
Upland VII	286	0.06±0.03	0.01±0.01	-83	n.s.
Totals	**2271**	**0.37±0.02**	**0.71±0.03**	**92**	**p<0.0001**

4.3.2 Relationship between main sett numbers and incidence of field signs, within land class groups.

The relationships between main sett numbers and badger field signs in the 1980s and 1990s were investigated for each land class group. Using main sett number as the dependent variable, there was a positive, significant relationship with activity score in each of the land class groups. However, in each group the slope of the line was steeper in the 1990s, except for Upland VII (Table 4.4), suggesting that as number of main setts increases, activity scores increased at a faster rate in the 1990s. The pattern was repeated with dung pit scores alone (Table 4.5). Also, the intercept value was higher in each groups in the 1990s (apart from Upland VII), suggesting that in squares without main setts, there is likely to be more field signs.

Table 4.4 Regression values for the relationship between badger main setts and activity scores.

Land class group	Regression slope, 1980s	Intercept	Regression slope, 1990s	Intercept
Arable I	5.32	1.43	6.05	1.93
Arable II	4.64	0.28	5.90	1.51
Arable III	2.55	0.28	5.19	0.47
Pastoral IV	3.62	1.60	5.20	2.78
Pastoral V	5.02	0.71	5.26	1.70
Marginal upland VI	4.10	0.40	5.76	0.92
Upland VII	3.77	0.23	2.39	0.21

Table 4.5 Regression values for the relationship between badger main setts and dung pit scores.

Land class group	Regression slope, 1980s	Intercept	Regression slope, 1990s	Intercept
Arable I	1.47	0.29	1.72	0.44
Arable II	1.09	0.14	1.58	0.34
Arable III	0.65	0.55	1.25	0.16
Pastoral IV	0.87	0.26	1.54	0.48
Pastoral V	1.13	0.13	1.53	0.38
Marginal upland VI	1.18	0.06	1.92	0.21
Upland VII	0.95	0.05	0.59	0.00

The regression assumptions of linearity and normality of the dependent variable with respect to the independent variable were not met for these data, so it was not possible to test for the significance of the difference in the slopes of the line. However, there appeared to be a trend that for a given main sett number, there was a higher level of activity in the 1990s than the 1980s. To verify this, squares were selected which had at least one main sett in the 1980s and had the same number in the 1990s, thus factoring out any effects due to changes in the number of social groups within the 1-km squares. Of the 232 1-km squares of this type, 156 (67%) had higher activity scores in the 1990s (Wilcoxon $z = -6.85$, $p<0.0001$).

Additionally, the percent change in main sett density by land class group did not correlate with the percent change in activity score ($r_s=0.51$, n.s.) which suggested that the increase in activity score was not solely due to the increase in the distribution of badger social groups. To further test the idea that the increase in activity within the 1-km squares was at least in part due to larger groups, the increase in number of active holes per main sett (Table 3.14), which reflect group size (section 5.4.1), and the increase in activity scores were compared. They were found to be correlated ($r_s=0.77$, $p=0.07$). This can be viewed graphically in Figure 4.1. For the same density of social groups, there are higher activity scores in the 1990s than in the 1980s.

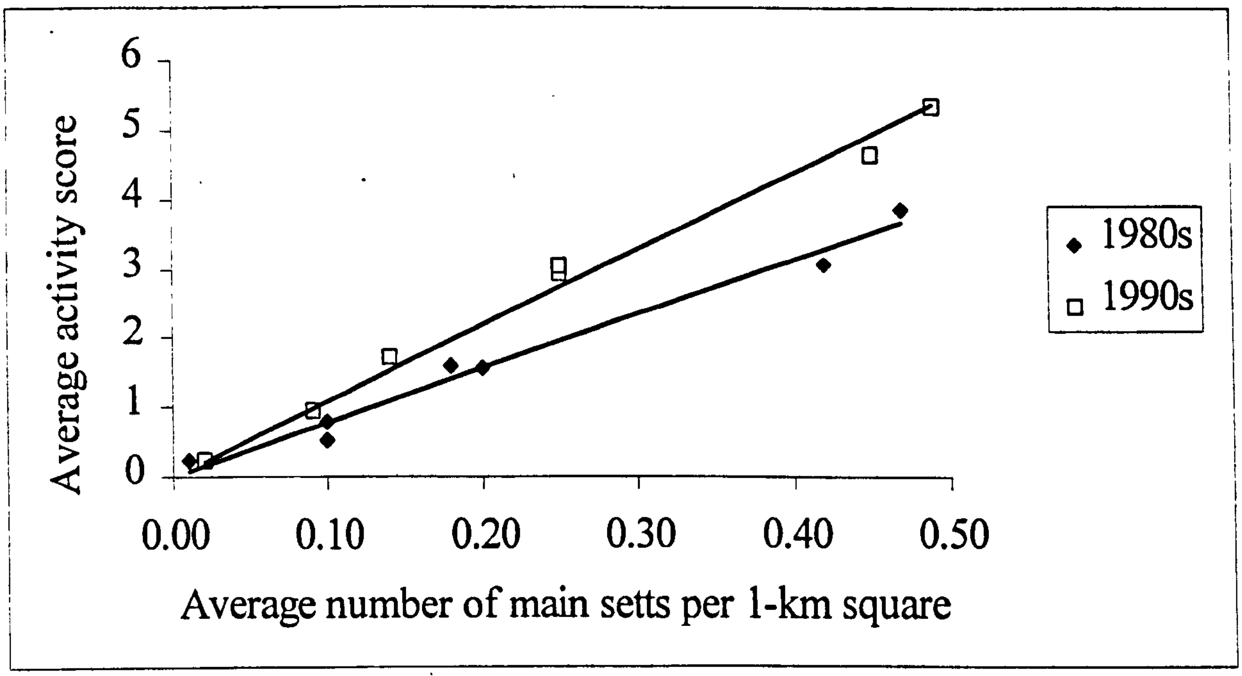


Figure 4.1 Average activity score per 1-km square against average number of main setts per 1-km square, by land class group

The remainder of this observed increase in activity was attributable to field sign incidence in squares which did not contain social groups. In the 1980s, there were social groups present in 17% of the squares, while there were field signs of some sort in 31% of the squares. In the 1990s, these figures were 22% and 38% respectively. A slightly higher proportion of the activity signs observed in the 1990s was contained in squares where there were no badger main setts recorded. This implies that more often in the 1990s than in the 1980s, there was badger presence in squares adjacent to, and with activity patterns overlapping with the survey squares. Some of the increase in activity levels within the sample squares, therefore, is attributable to the increased distribution of social groups, and some to the increase in within-group sizes.

4.3.3 The effect of survey date

Because badgers are less active in the period from mid-November to mid-January, it was possible that the incidence of field signs found could be influenced by the timing of the survey fieldwork: different proportions of the 1-km squares being surveyed within this time period between the two surveys could, in theory, lead to a bias in dung pit and/or activity score values. In the 1980s, 761 of the 2115 1-km squares (36%) for which the date of survey was known were surveyed in this 'low activity' period, whilst in the 1990s this figure was 40%. The 1980s data on activity score and dung-pit score from squares surveyed within this three month period were compared with those from the remainder of the squares, for each land class group. There were no significant differences in the levels of activity found in the 'low-activity' season. Therefore the methodology was robust to the timing of the fieldwork.

Table 4.6 Difference in mean dung pit score between low-activity season and rest of survey period, for the 1980s.

Land class group	Mean dung-pit score, Feb-Oct (n)	Mean dung-pit score, Nov-Jan (n)	Mann-Whitney z	significance
Arable I	1.0 (159)	1.1 (32)	-1.9	n.s.
Arable II	0.4 (336)	0.2 (111)	-1.4	n.s.
Arable III	0.1 (112)	0.1 (66)	-0.7	n.s.
Pastoral IV	0.7 (290)	0.5 (113)	-0.9	n.s.
Pastoral V	0.3 (223)	0.3 (91)	-0.5	n.s.
Marginal upland VI	0.2 (211)	0.1 (94)	-0.6	n.s.
Upland VII	0.1 (202)	0.0 (74)	-1.4	n.s.

Table 4.7 Difference in mean activity score between low-activity season and rest of survey period, for the 1980s.

Land class group	Mean activity score, Feb-Oct	Mean activity score, Nov-Jan	Mann-Whitney z	significance
Arable I	3.9 (159)	4.2 (32)	-0.7	n.s.
Arable I	1.6 (336)	1.3 (111)	-0.3	n.s.
Arable I	0.5 (112)	0.5 (66)	-0.3	n.s.
Pastoral IV	3.3 (290)	2.7 (113)	-0.9	n.s.
Pastoral V	1.6 (223)	1.4 (91)	-1.3	n.s.
Marginal upland VI	0.9 (211)	0.8 (94)	-1.0	n.s.
Upland VII	0.3 (202)	0.1 (74)	-0.8	n.s.

4.3.4 Relationship between main sett numbers and incidence of field signs between land class groups

To further compare badger social group numbers and field signs, comparisons between the land class groups were carried out. For the first step, activity score was related to main setts by plotting mean activity score against main sett density in the 1980s. The assumptions for carrying out regression analysis were checked, for both dung pit scores and activity scores. The relationship between mean number of badgers per square and both dung pit and activity scores per square were linear, and the residuals for both were not significantly different from normal (dung pits: K-S = 0.23, $p > 0.2$, activity: K-S = 0.21, $p > 0.2$), so regression was a valid technique. The results for the relationship between average number of main setts per square and average activity score per square for the land class groups are shown in Figure 4.2.

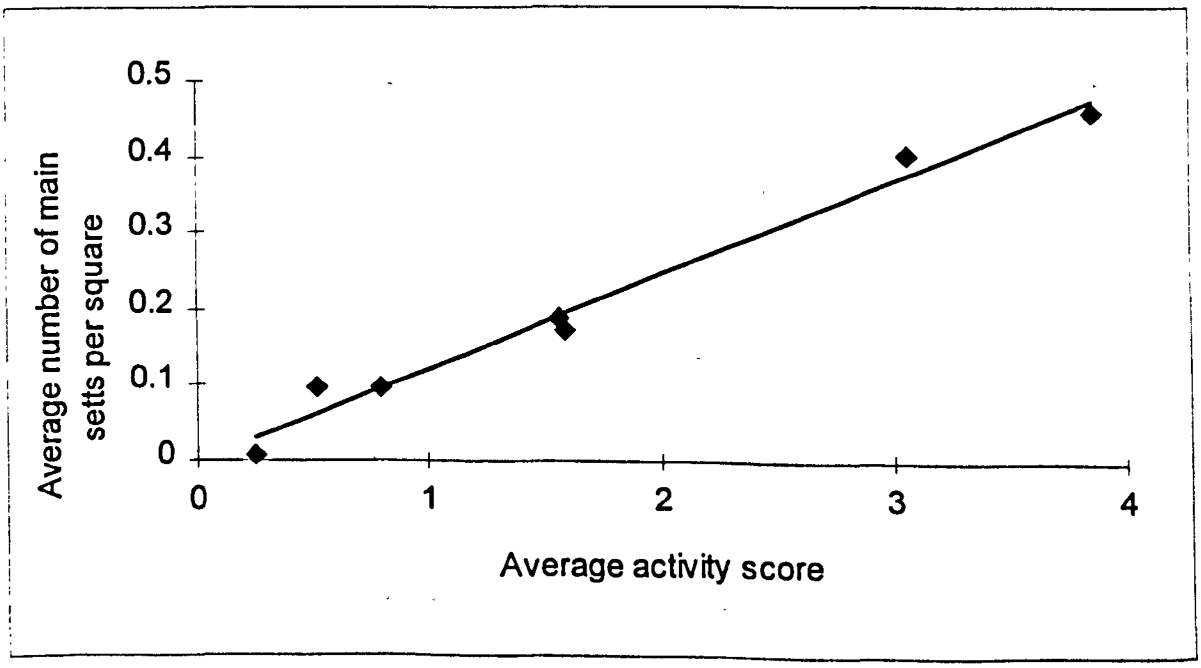


Figure 4.2 Average number of main setts per square against average activity score per square, by land class group ($y = 0.123x - 0.001$, $R^2 = 0.98$, $p<0.05$)

When averaged out over a large sample, the level of badger activity across a given area relates closely to the number of social groups. Therefore, for any large sample of squares, the incidence of field signs observed using this survey protocol gives a value from which the average number of main setts per square (or a measure of density) can be predicted. Using this rationale, the values for number of main setts per square that would be predicted by the level of field sign incidence in the 1990s were calculated by applying the regression equation from the above relationship to the 1990s activity score data. The predicted values and the 95% confidence intervals (Zar, 1996) are shown in Table 4.8.

Table 4.8 Average number of main setts per square from the survey sett data in the 1980s and 1990s, and the predicted value for the 1990s from the regression analysis.

Land class group	Main setts per square, 1980s	Main setts per square, 1990s - actual	Main setts per square 1990s - predicted from regression	*Lower 95% CI*	*Upper 95% CI*
Arable I	0.46	0.45	0.57	*0.52*	*0.61*
Arable II	0.19	0.25	0.36	*0.33*	*0.38*
Arable III	0.10	0.09	0.11	*0.09*	*0.13*
Pastoral IV	0.40	0.49	0.65	*0.60*	*0.70*
Pastoral V	0.17	0.25	0.37	*0.34*	*0.39*
Marginal upland VI	0.10	0.14	0.20	*0.18*	*0.23*
Upland VII	0.01	0.02	0.03	*0.00*	*0.05*

The predicted densities of main setts are considerably higher than the actual values produced from the survey (Table 3.3). This is because, on average, the field sign incidence for each social group is higher in the 1990s due to the groups being larger.

4.3.5 Relationship between badger numbers and activity score, by land class groups

To investigate the relationship between badgers numbers and activity score, main sett density was converted to badger density by multiplying the mean number of main setts per square by a constant, average group size of 5.9 adult badgers, as described in section 4.2.2. Figure 4.3 shows the relationship between mean number of badgers per square and mean activity score per square. This is essentially the same line as in Figure 4.2, with the y-axis modified to represent badger numbers instead of main sett numbers. This was assumed to be the relationship, between number of badgers and incidence of field signs.To calculate the change in badger numbers in Britain between the two surveys, estimates had to be made for the 1980s and the 1990s. Firstly, the number of badgers in the 1980s was calculated by extrapolating the values for mean badgers per square, in each of the land class groups, to the whole country (Table 4.9). Secondly, the estimated number of badgers in Britain in the nineties was predicted from the activity scores, by applying the regression equation to the values for mean activity in the 1990s as before.

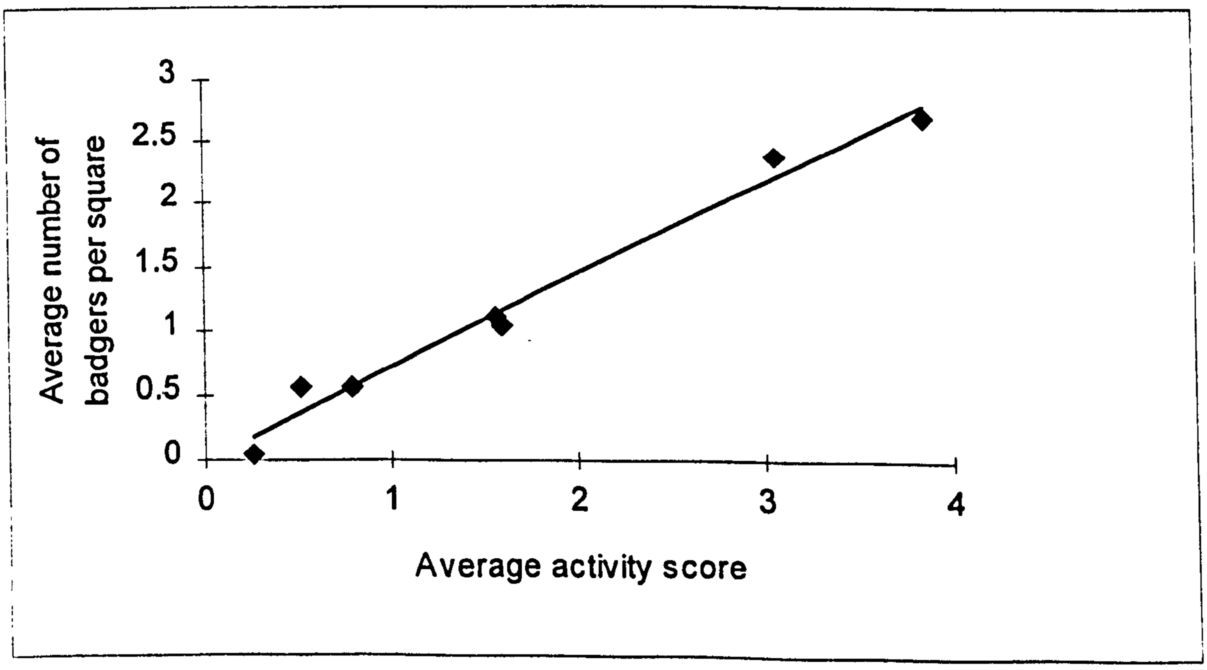


Figure 4.3 Average number of badgers per 1-km square against average activity score per square, by land class group. ($y = 0.725x - 0.006$, $R^2 = 0.98$, $p<0.05$)

Table 4.10 shows the mean activity scores 1990s, and estimated number of badgers, with prediction confidence intervals. These figures represent an increase in the total number of badgers in Britain of 75% ± 17%. The same procedure was carried out using dung pit scores alone, and the difference was found to be 78% ± 33%. The large confidence intervals are due to the fact that there are only seven land classes, or points on the regression line. Only very strong relationships can be detected with any kind of certainty with less than 20 points on a regression line. Having only seven points leads inevitably leads to uncertainty, despite the strength of the relationship. Activity scores and dung-pit scores produce similar estimates of the proportional change in badger numbers, but the former produce a considerably more accurate estimate. Therefore, activity scores will be used in the following analyses.

Table 4.9 Estimate of the number of badgers in Britain in the 1980s, based on an assumed mean group size of 5.9.

Land class group	Average number of social groups per square	Average number of badgers per square	Total number of squares	Total number of badgers
Arable I	0.46	2.6963	14,460	38,988
Arable II	0.19	1.1151	48,385	53,954
Arable III	0.10	0.5664	18,339	10,387
Pastoral IV	0.40	2.3836	34,730	82,782
Pastoral V	0.17	1.0266	35,383	36,324
Marginal upland VI	0.10	0.5664	35,438	20,072
Upland VII	0.01	0.0413	45,150	1865
Totals	-	-	**231,885**	**244,373**

Table 4.10 Predicted number of badgers in the 1990s, based on the known mean activity scores for each land class group.

Land class group	Mean activity score, 1990s	Predicted badgers per square, 1990s	*Predicted badgers per square 1990s, lower 95% CI*	*Predicted badgers per square 1990s, upper 95% CI*	Number of squares in land class group	Numbers of badgers, 1990s	*Numbers of badgers 1990s, lower 95%CI*	*Numbers of badgers 1990s, upper 95% CI*
Arable I	4.66	3.37	*3.19*	*3.55*	14,463	48,739	*44,710*	*52,789*
Arable II	2.94	2.12	*1.98*	*2.26*	48,683	102,785	*94,839*	*111,998*
Arable III	0.94	0.68	*0.54*	*0.81*	18,358	12,381	*10,497*	*14,291*
Pastoral IV	5.34	3.86	*3.66*	*4.06*	24,848	134,175	*123,388*	*145,873*
Pastoral V	3.03	2.19	*2.05*	*2.33*	35,325	77,472	*70,944*	*83,747*
Marginal upland VI	1.71	1.23	*1.10*	*1.36*	35,233	43,697	*39,240*	*47,624*
Upland VII	0.26	0.18	*0.04*	*0.32*	45,032	8235	*3255*	*13,172*
Totals	-	-	-	-	**231,932**	**427,486**	***386,874***	***469,494***

4.3.6 Relationship between badger numbers and activity score, by land classes

To investigate the robustness of this methodology, a similar procedure was carried out at a finer scale, using average values for badger numbers and field signs for each of the 32 land classes from which the seven land class groups are made up of (Chapter one). The total number of badgers in the 1980s was estimated to be 250,093 using the 32 land classes. This figure is slightly different to that produced when using the land class groups, but only by 2%. The relationship between activity scores and mean number of badgers per square is shown in Figure 4.4.

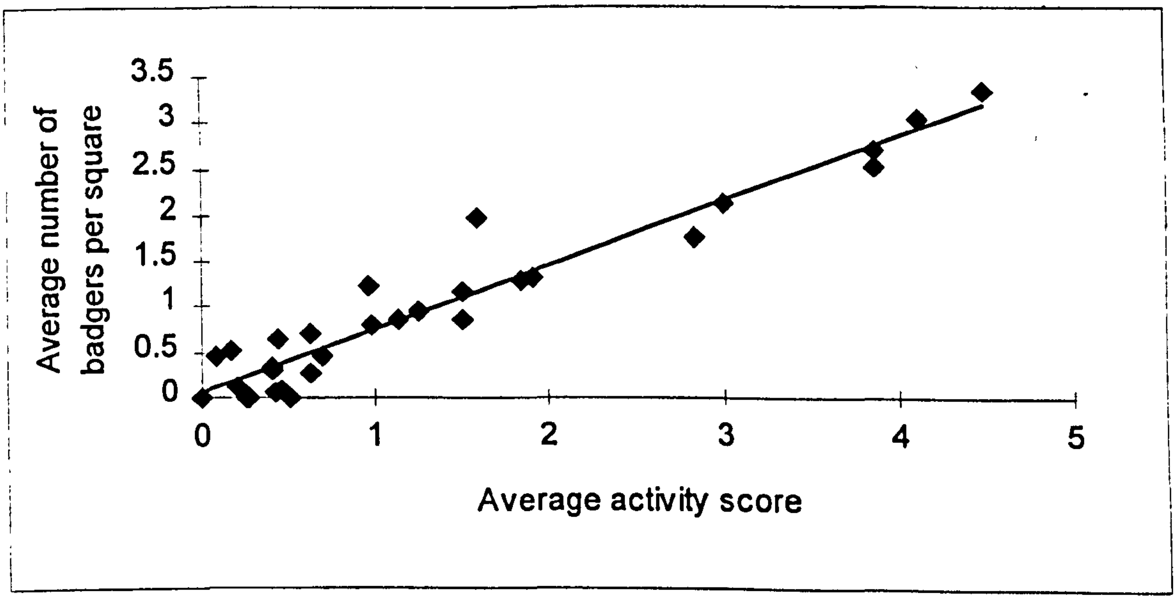


Figure 4.4 Average number of badgers against average activity score per square, for each land class ($y = 0.700x+0.05$, $R^2 = 0.93$, $p<0.05$).

The predicted increase in the total number of badgers based on the activity scores in the 1990s, using the same method as with land class groups was 75% ± 9%. This is a very similar result to when the analysis is carried out by land class group, but due to the greater number of points, the 95% confidence intervals are smaller.

4.3.7 Relationship between badger numbers and activity score, by region

In Chapter three, the differences in numbers of setts were documented both by land class group and by region. 1-km squares of individual land classes, and thence land class groups are identified by being comprised of characteristic combinations of potentially biologically significant physical features. On a regional basis, there is no such stratification, and there are 1-km squares of several land class groups in each region. It is true, however, that any given region is likely to have an abundance of squares of a particular land class group. By carrying out the above analysis by region, it was possible to further test both the robustness of this method, and investigate the influence of landscape homogeneity on the estimate of change. Badgers per 1-km square were plotted against activity score per 1-km square by region. The relationship is shown in Figure 4.5. By applying the equation of this relationship to the average activity scores in the 1990s as in section 4.3.5, the increase in number of badgers was found to be 68% ± 20%. This figure is of similar magnitude to that produced when land class groups or land classes are used. Grouping the sample squares by land class group does appear to produce a different estimate of change in badger numbers than when the procedure is carried out by region, but this difference is not large. The 95% confidence intervals are larger than when land class groups are used, due to the increased spread of points around the line.

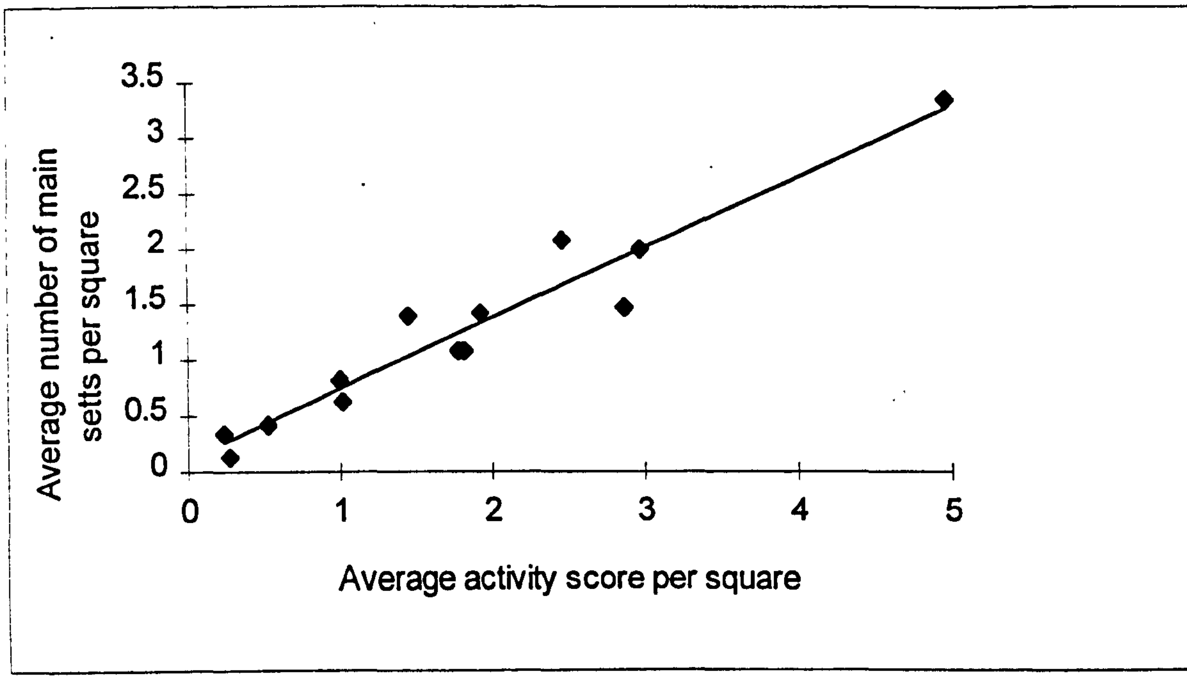


Figure 4.5 Relationship between average number of main setts per square, and average activity score per square, in the 1980s, by region. (y = 0.64x+0.10, R^2 = 0.93, p<0.05).

4.3.8 Relationship between changes in badger numbers and changes in badger social group number

To investigate how the change in number badgers, as predicted from the activity scores, relates to the observed change in number of social groups, the two were plotted against each other (Figure 4.6). There was a positive, straight line relationship, with the line cutting the x - axis at a point relating to a 25% increase in number of badgers. This suggests that an increase in number of social groups is noticeable with our survey protocol after the number of badgers has increased beyond 25%, on average. The values used for this relationship are subject to variation and assumption. The constant group size assumption, and the confidence intervals associated with both the 1980s badger densities and the regression-predicted 1990s values for badger density, will both affect the slope of the line. However it seems biologically plausible to expect that badger numbers will increase initially by means of increasing group size, then by establishment of new groups.

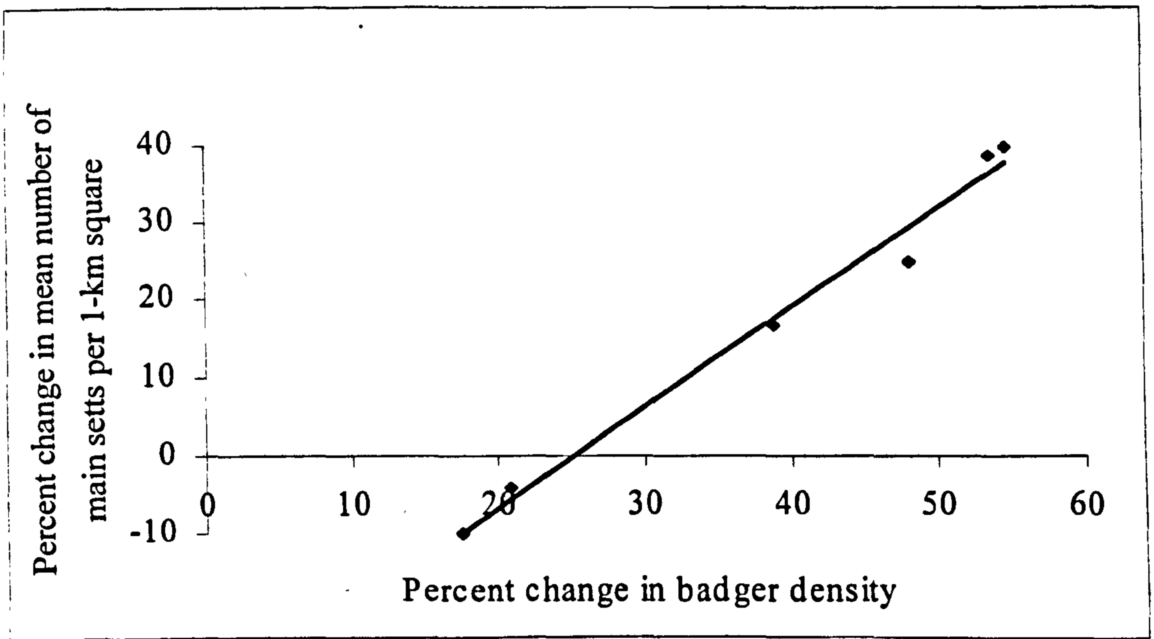


Figure 4.6 Relationship between percent change in badger numbers (from Tables 4.7 and 4.8) and percent change in the average number of badger social groups per square (from Table 3.3), by land class group.

4.3.9 Changes in group size

The above analyses indicate an increase in badger numbers of around 75%. Given that there was a 24% increase in numbers of social groups, and assuming an mean group size of 5.9 in the 1980s, it is possible to calculate the average increase in group size required to produce 75% badger population increase. The average increase in group size required to bring this about is 41%, (2.4 individuals). This value is the mid-point of the range 37% to 45% (2.2 to 2.7 individuals) when the 95% confidence intervals around the estimate of change (section 4.3.6) are taken into account.

4.4 Discussion

In this Chapter, a simple field sign index was used to estimate proportional change in the total number of badgers in Britain. Badger numbers in Britain were estimated to have increased by around 75% in the period between the surveys. In the absence of reliable data on typical badger group sizes in different habitat and landscape types, this is necessarily a crude estimate, based on the assumption of a uniform group size. The relatively wide confidence intervals associated with the predicted values for change in badger numbers also have to be taken into account. However, the analysis is valuable in that it highlights the fact that the badger population has grown considerably more than the increase in social group numbers alone might suggest: the population has grown via the two modes of group size increase and increase in numbers of groups. An insight is also gained into the mechanism of badger population growth i.e. how much is due to group size change or group number change. This method is applicable only at a large scale, with large samples of 1-km squares, as in this survey. At a local scale, the crude field sign index used would be not be sensitive to the variability associated with individual badger group movements, territorial behaviour, and social group size, and the fine scale differences in field-sign incidence that these variations would entail.

The use of a constant, mean group size of 5.9 adult badgers also must be addressed. This was assumed to be the average group size at the time of the original badger survey, derived from a number of studies, primarily from good badger habitat (Cresswell, Harris & Jefferies, 1990). This figure was not weighted in any way for differential group sizes in different habitats and/or geographical regions, or differential densities of main setts. It is conceivable that in the 1980s, for the majority of lowland Britain this figure was too high, resulting in an erroneously high estimate for number of badgers in Britain as a whole. Also, badger group size can be very variable. Groups range from one or two adults in low density areas (Kruuk & Parish, 1982) to very large groups in prime badger habitats, the largest recorded being 27 individuals (Rogers et al. 1997). Group size may typically differ between land class groups and / or regions, but data do not exist to validate this. However, in large samples such as those used in the analyses using land class groups, which cover large geographical areas of the country, the average group size is unlikely to vary greatly and it provides a suitable starting point. Altering the value produces only small differences in the resultant proportional change estimates between the two surveys. If further research were to produce different typical group sizes between land class groups, then these could be incorporated into the analyses, and the results refined.

The two field sign indices investigated, dung pit scores and activity scores gave similar estimates of change in badger numbers. However, there was greater confidence associated with the estimate using activity score. Analysing the data by region gave a slightly different estimated change value, and there was more variation in activity scores with respect to badger density. This is due to the uniformity of the 1-km squares in the land class groupings, in terms of habitat: the likelihood of finding field signs, with this survey protocol, is consistent with the density of badgers. The variability in the habitat character of squares within the regions used here has some influence on the levels of field signs which will be found by surveyors. The difference is not great, but nevertheless, using land class groupings is more accurate for these analyses.

The question as to why exactly activity scores increase with increasing group size remains unanswered. Territory boundaries are known to remain invariant in size irrespective of changes in the size of the resident group (Kruuk, 1982). However, badgers spend much of their time foraging alone, therefore it is seems likely that a larger proportion of a group's territory will be visited regularly when more animals are present. This would lead to increased incidence of field signs throughout the area, and an increased probability of discovery by surveyors. Also, as groups become large, they are more inclined to be distributed throughout the territory for much of the year (Chris Newman, *pers. comm.*). This would again lead to greater likelihood of field sign discovery by surveyors across a larger area.

The results are in broad agreement with the two intensive, longditudinal studies on badger demography. In the M.A.F.F. study at Woodchester Park on the demography of an area of 21 contiguous social groups, the group sizes have increased markedly in recent years. The mean group size increased from 5.3 to 8.8 from 1985 to 1994 (Rogers *et a,l* 1997), approximately the same time period between the two surveys. This corresponds to an increase of 66%. At Wytham Woods near Oxford, badger density rose from 8.7 adults per 1-km2 in 1978 to 16.7 adults per 1-km2 in 1989, an increase of 87% (Woodroffe 1992). These increases are in the same region as the estimate of total change in badger numbers produced in the analyses in this Chapter. The extents of the increase in group size in these studies are beyond what I have estimated to have occurred nationwide: a 45% increase on average was estimated to have been required to result the 75% increase badger numbers, given a 24% increase in social group number. Situated as they are in what is considered to be prime badger habitat, in the areas of highest badger density in the country (Rogers *et al*, 1997), they are not typical sites. But it is clear that the increases in group size in these studies are not isolated cases: the trend of increasing group size has been repeated over much of the country.The prediction that, on average, after an increase in badger numbers of 20-30%, new groups begin to be established is revealing in terms of how badger populations grow. Locally, this pattern will vary according to the existing conditions in any given area: badger density, carrying capacity of the habitat, availability new main sites will all effect the level at which new groups will begin to appear. Indeed, the Woodchester study does not directly support the theory. Despite the marked increase in the population through group size growth, the number of social groups remained constant. The situation at Woodchester, however, is unlikely to be typical of the rest of the countryside. It appears to represent optimal habitat due to the surrounding land use and underlying soil type. Therefore it is possible that the area is 'saturated' with badger social groups. Roper (1993) proposed that suitable sites for main sett construction were a limiting resource, and that distribution of main setts was determined ultimately by the availability of these sites. If this is the case then the only mechanism by which the badger population can grow in an area such as Woodchester is through increasing group size. This is unlikely to be the situation throughout much of Britain, where only 25% of lowland 1-km squares contained main setts, suggesting that there could well be suitable habitat for the establishment of new social groups.

Since a higher proportion of females raise cubs in small social groups than in larger ones (Woodroffe and Macdonald, 1995), it could be advantageous in terms of reproductive success for females to move once group size becomes large. Although studies have shown that only a small proportion of badgers leave their natal groups (Cheeseman *et al.* 1988), there is evidence to suggest that females disperse more readily from larger groups, with an associated increase in reproductive success (Woodroffe *et al.* 1993). The results presented may also help to explain the speed of recolonisation of badgers into cleared areas; it will be in part dependent on the size of the groups in surrounding areas.

4.5 Summary

In this Chapter, the field sign index developed for the survey provided a means of estimating the change in relative abundance of badgers between the two surveys. The findings complimented the results presented on changes in sett numbers in Chapter three. The number of badgers in Britain was estimated to have increased by around 75%. To have achieved this, given a 24% increase in social groups, an average increase in group size of 45% would have been required. These results are in parallel with the disproportionate increases in sett size, and number of smaller setts reported in the previous Chapter.

The relationships between the size of social groups, main sett size and size and number of smaller setts within a territory, provide an alternative perspective in attempting to assess the extent of change in numbers between the two surveys. These are explored in Chapter five.

5. Estimation of badger abundance from field signs

5.1 Introduction

The comparison of two population estimates to detect a change, based on social group density, depends on the mean group size remaining unchanged throughout the intervening period. The results presented in Chapters three and four clearly show that this is not the case with badgers in Britain. Also, lack of data on the variability of group size throughout the country renders it problematical to make population estimates; using a constant mean group size does not weight the estimate for group size variation: an un-weighted estimate fails to account for the possibility that areas (regions or land class groups) of different densities of social groups may typically have different group sizes. This would almost certainly result in an inaccurate estimate of the size of the overall badger population. Estimation of actual badger numbers in both national surveys, therefore, could not be carried out with confidence.

In Chapter four, a simple field sign index was utilised to estimate the change in relative abundance in badger numbers from 1988 to 1997, which provided an idea of the extent of the badger population increase and complemented the results of the changes in numbers of social groups documented in Chapter three. However, actual figures for badger numbers in the surveys remained unknown.

Knowledge of the patterns of abundance, distribution and density of mammals is often an important requirement in the field of functional ecology. Successful studies of predator-prey interactions, economic damage by mammals, and studies into disease transmission to name but a few hinge on reliable estimates of animal abundance. It is often difficult, labour intensive, or both to achieve such estimates. Methods based on capture-mark-recapture are the most commonly used, and have led to the development of numerous statistically robust models (Montgomery, 1987). Because of the intensive work required to carry out such studies, investigations are often restricted to a small spatial scale, when much larger scale data are required. In view of this, a number of attempts have been made to estimate animal abundance using easily collected field sign data associated with the ecology of the species in question. For example, patterns of latrine production by water voles *(Arvicola terrestris)* have been used as indices of abundance in population surveys (Woodroffe & Lawton, 1990). Similar techniques have been applied to field voles using evidence of grazing intensity and runways as indices (Hansson, 1979), and deer (*Odocoileus virginianus*) using faecal counts and track counts (Mooty & Karns, 1984).

Evaluation of badger abundance in any given area profits greatly from their social behaviour. Main setts are reliable indicators of the presence of a social group. At a local scale, counts by direct enumeration can give an accurate picture of badger distribution and some measure of abundance. At a large scale, as with the national survey, stratified survey techniques and extrapolation can be used effectively. Clearly, however, this deals only with social group numbers. True enumeration of badger numbers can only be achieved if the size of social groups as well as the number of social groups is known. Social group size can be very variable, even at a limited spacial scale (Rogers *et al.*, 1997). This presents considerably more difficulties, as it is inherently difficult to assess how many badgers are in any given social group without carrying out laborious capture-mark-recapture studies. As already mentioned, how group sizes vary across the country is not known, although they appear to be larger on average in more optimum habitat (Kruuk & Parish, 1982), but the determinants of group size are not simple.

In parallel with the increase in numbers of social groups in Britain as a whole and average activity scores, it was also reported in Chapter three that there had been an increase in average badger sett size (particularly active holes) between the surveys. Therefore it appeared possible that a relationship existed between resident badger numbers and sett size, at least for a given habitat or substrate. Anecdotal evidence from a number of surveyors involved with data collection on this project suggested that the number of very active holes fluctuates at their local sett in parallel with changes in the social group.

It has been suggested the size of badger main setts is a correlate of age rather than group size in any given substrate, as badgers are known to continue excavating and extending the setts over time (Kruuk, 1978; Neal & Roper, 1991), but that this is relationship is confused by the effects by disused entrances becoming blocked, both naturally and through the activities of man. However, it is also apparent that badgers can very quickly excavate large setts in a short period of time. It could be argued that setts were larger simply because of the greater age of those setts which were recorded in both surveys. This possibility is also investigated in this Chapter.

A consistent relationship between group size and size / activity of the main sett (and other setts within the territory) would therefore allow the estimation of badger numbers from sett data and would dispose of the need of using a constant mean group size value. The survey results could be refined based on the sett data held, and the findings in Chapter four could be tested by a separate analysis from a second approach.

The aim of this section, therefore, was to carry out a pilot study investigating methods of estimating the number of individuals in a group, specifically adult badgers, from field signs. It was intended that most attention be paid to those variables collected in the course of the national surveys, in order that any reliable relationships could be incorporated into the national database, thus refining the results. As outlined previously, during the repeated badger surveys, data were collected on number of active, partially used and disused holes for each sett recorded, and so they were the primary parameters of interest in this pilot.

The opportunity was taken to gather territory size / latrine use data for the groups studied, to investigate the possibility that estimating numbers at a more local scale i.e, the number of badgers in any given group would be improved by the inclusion of latrine use data in any predictive model.

5.2 Methods

Data from badger social groups in a variety of habitats were required. To this end, in addition to myself studying five contiguous social groups in an area in Wiltshire, surveyor help was solicited from two main sources: people who had surveyed squares of the national survey, and badger protection groups affiliated with the National Federation of Badger Groups. People who had in-depth local knowledge of one or more badger social groups through regular sett monitoring and badger watching were enlisted to take part in the data collection. The data recording forms and instruction sheets used are shown in Appendix 11.10. Fieldwork was carried out during the peak territorial marking period in March - April, when latrines are heavily used, and when vegetation was still low, enabling easier and more thorough surveying. The sett watches to ascertain group size were carried out in May, when observation in the evening became possible due to lengthening daylight. Group size was investigated with respect to number and activity of setts, and patterns of latrine use.

The data were collected in three stages:

1. Territorial boundary established

Bait-marking was used to delineate the territory of the groups being studied. Indigestible coloured pellets were introduced into a bait mixture attractive to badgers in the standard manner as described in Harris *et al.* (1994). This was fed to the groups over a period of fourteen days as recommended, after which the area was searched for pellet returns in latrines in the surrounding area.

2. Setts and latrine survey within the boundary

Location of all setts within the boundary were recorded on a map. The number of active, partially used and disused holes at each sett were recorded, in accordance with the national badger survey protocol. Additionally, soil type and slope at the sett site were recorded, but were not included in the following analyses due to their incompatibility with the national badger survey database. Locations of all the latrines in the area were also recorded on a map. The number of pits, number of fresh faeces, and number of faeces containing pellets were recorded at each latrine. Even on the boundary, all the fresh droppings in the latrine were counted as 'belonging' to that group. The implications of this are discussed in section 5.4.3.

The habitat, using the same habitat key as in the national badger survey, at each latrine location was recorded. A latrine was defined as group of dung-pits, from one - n, with at least one pit containing badger faeces. The latrines were entered into the database as follows:

1. Definitely within territory

2. Probably within territory - these were consistent with the territory boundary but did not contain coloured pellets as proof.

3. Probably outside territory - these were considerably beyond the extent of the furthest latrine with markers, and therefore assumed to be outside the group territory.

3. Group size estimation from regular observations

Data were collected from groups which were regularly watched, and from previous studies carried out at Bristol (M.R.Hutchings, *pers. comm.*). In many cases, the observers were familiar with the individuals within the group, and had tracked fluctuations in the group occupancy for years. For those groups where this level of detail was not available, watches were carried out to estimate the group size. Where possible, all setts within the territory boundary were watched simultaneously, to ensure accurate estimation of number of individuals. Also to this end, several watches were carried out. Each record was given a credit rating relating to a number of factors: the number of unwatched setts in the territory where there was a possibility of badgers in residence, the number of watches undertaken, the ease with which the sett(s) could be viewed and the confidence the observers had in their results. These were considered and a rating of 1-3 given as follows:

1: Confident in the results - group size assured.

2: Group size estimate probably correct, but few watches undertaken, or other outlier setts not watched and possibility of underestimation of group size.

3: Little confidence in estimate, due to unsuccessful watches, or impaired view of sett(s) due to undergrowth.

Only groups with credit rating "1" or "2" for the above were used in the analyses. 33 social groups fell into these categories, and could be used in analyses involving sett sizes and group sizes. Bait-marking was carried out on only a proportion of these. Cases for which baitmarking was successful, but which had a credit rating of "3" for the group size estimate were not used in the analyses (n=5). Ten of the 33 groups had a successful bait-marking exercise carried out on them. For one of these, the surveyor did not record hole details of the main sett. Therefore, in the analysis of group size variation with respect to extent of fresh dung deposition, n = 9. Of these, three were from Arable I, one from Arable II, four from Pastoral IV and two from Pastoral V.

5.2.1 Data analysis

Bivariate correlations were used to establish the relationships between group size and the field sign variables. Regression analysis was used to predict group size from main sett active hole numbers from the survey databases of the 1980s and 1990s. Multiple linear regression was used to investigate the interrelations between group size, and main sett active hole and latrine use.

5.3 Results

5.3.1 Group size and sett size

The sample of social groups were distributed unevenly across the land class groups, with zero occurring in Upland VII, and a maximum of 13 occurring in Pastoral IV. Because of this, and the small sample size which would result from dividing up the sample by land class group, the data were pooled for the analyses. Sett details are given in Table 5.1. The mean adult group size for the 33 social groups studied was 6.06 (s.e.= 0.45), with a range of 2 to 12 adult badgers. Timing of first emergence of badger cubs is variable. Because the fieldwork was undertaken early in the breeding season, many of the groups recorded a zero return for number of cubs. Long-term capture-mark-recapture in two high density populations showed that 35% of social groups fail to breed each year (C.L. Cheeseman & S. Harris, *unpublished results*).

Table 5.1 Mean number of entrance holes for main setts, and for all other setts combined, (n=33 social groups).

	main sett active holes	main sett partially-used holes	main sett disused holes	other setts combined active holes	other setts combined partially-used holes	other setts combined disused holes
Mean	8.18	3.30	2.42	3.55	2.18	2.94
s.e.	0.65	0.49	0.48	0.96	0.60	0.98

Because of the variability in timing of first emergence by cubs, and the impossibility of determining whether a given group had failed to breed or the cubs had simply not emerged at the time of the observations, the data on cub numbers were not used in these analyses. This was not a problem since the aim of the pilot was the estimation of the adult population size.

Group size in this chapter refers to the number of adult badgers.

5.3.2 Relationships between group size and sett parameters

To establish whether there were any simple relationships between the size and number of setts, a bivariate correlation matrix was produced. The following variables were plotted against group size: main sett active holes; all holes at main sett; partially used holes at main sett; combined active and partially used holes at main sett; number of setts in territory; total number of active holes at all setts in territory. Main sett active holes correlated best with group size ($r = 0.80, p < 0.001$). The only other variables which correlated significantly were: all holes at main sett ($r = 0.43, p = 0.01$), number of active and partially used holes combined ($r = 0.65, p < 0.001$) and total number of active holes at all setts in territory ($r = 0.59, p < 0.001$). None of these were an improvement, and were in any case confounded in that the main sett active holes variable was large component of each of them. The relationship between group size and main sett active holes is shown in Figure 5.1.

Main sett active hole numbers, therefore, explained 64% of the variation in number of adult badgers in the group, with regression equation:

$$\textit{Group size} = 0.55 \times \textit{Active holes} + 1.55$$

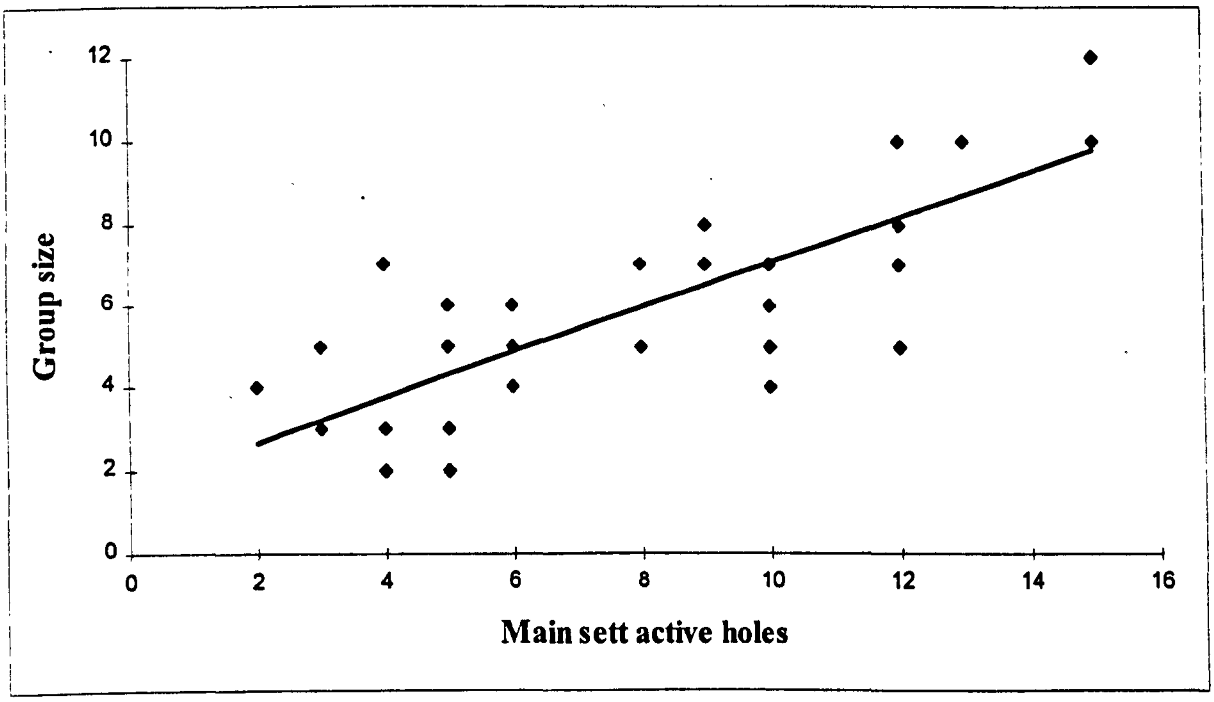


Figure 5.1 The relationship between group size and number of active holes at main setts ($y = 0.55x + 1.55$, $R^2 = 0.64$).

The distribution of the residuals around the regression line were not significantly different from normal (Shapiro-Wilks = 0.98, n.s.) and the relationship was linear, and so the assumptions for regression were met.

5.3.3 Population estimates using sett size

The sett sizes in terms of number of active holes at main setts from the repeated surveys were used, with the equation from the above relationship to predict badger numbers nationally in the 1980s and 1990s. The above regression equation was applied equally to all main sett data on a square by square basis, to provide an estimate of group size for each sett recorded, including 95% confidence intervals. The results were then grouped by land class group to produce a value for average number of badgers per main sett in each group, 1980s and 1990s.

The estimates for number of main setts in each land class group as presented in Chapter three, were then used: the estimated number of badgers in each land class group was calculated as the product of the number of main setts and average number of badgers per social group.

Table 5.2 Estimated number of badgers in Britain in the 1980s, using sett size to predict group size, by land class group

Land class group	Estimated number of main setts	Mean group size	Total badgers
Arable I	6436	4.83	31,109
Arable II	8925	4.68	41,766
Arable III	1706	3.96	6751
Pastoral IV	13,721	5.22	71,630
Pastoral V	5928	4.57	27,105
Marginal upland VI	3375	4.14	13,955
Upland VII	308	3.48	1071
Total (± 95% C.I.)		**4.79**	**193,387 ± 37,031**

Table 5.3 Number of badgers in Britain in the 1990s, using sett size to predict group size, by land class group.

Land class group	Estimated number of main setts	Mean group size	Total badgers
Arable I	6366	6.16	39,214
Arable II	11381	6.32	71,960
Arable III	1600	4.48	7172
Pastoral IV	16743	6.48	108,507
Pastoral V	8586	5.95	51,070
Marginal upland VI	4816	5.76	27,750
Upland VII	749	4.30	3219
Total (± 95% C.I.)		**6.06**	**308892 ± 47,326**

The sett sizes in the 1990s predicted larger group sizes. The large confidence intervals are the result of the spread of points around the regression line, resulting in a range of possible values for group size at each sett. The upper and lower 95 % values for group size used in the calculation of the population confidence intervals are presented in Appendix Table 11.11. The predicted number of badgers was 193,387 in the 1980s and 308,892 in the 1990s, a difference of 60%. The overall average group size in the 1980s based on number of active main sett holes was 4.8, while in the 1990s the value was 6.06, an increase of 27%. There was an increase in group size in each land class group (Table 5.4).

It was possible that the larger setts in the 1990s were a consequence of the repeated squares sampling design. Many of the setts extant in the 1980s remained in the 1990s and were therefore at least nine years old and perhaps larger simply as a factor of greater age. If this was the case, then the setts in the repeated squares would be expected to be larger than those in the newly surveyed squares. The number of active holes per sett in the 1990s repeat squares were compared with those in the 307 squares which were sampled at the time of the 1990s survey, and which were previously unsurveyed. There was no significant difference (Mann-Whitney $z = -0.94$, n.s.). There were significantly fewer active holes per main sett in the 1980s than in the newly surveyed squares in the 1990s (Mann-Whitney $z = -3.06$, $p < 0.01$). Therefore the increased number of main sett active holes in the 1990s is not a factor of sett age in the repeated squares, but a genuine trend.

Table 5.4 Change in group size by land class group, as predicted from sett sizes, 1980s to 1990s.

Land class group	Group size, 1980s	Group size, 1990s	Percent increase
Arable I	4.83	6.16	22
Arable II	4.68	6.32	35
Arable III	3.96	4.48	13
Pastoral IV	5.22	6.48	24
Pastoral V	4.57	5.95	30
Marginal upland VI	4.14	5.76	39
Upland VII	3.48	4.30	24
Totals	**4.79**	**6.06**	**27**

There was no correlation between the percent change in number of main setts (Table 3.1) and percent change in group size by land class group ($r_s = 0.68$, n.s.).

Badger activity tends to be reduced during the period mid-November to mid-January. If this were reflected in the number of main sett active holes then clearly the relationship between that and group size would be different, hence ultimately producing a different population estimate. However, exploration of the badger survey data showed that in the 1980s, the number of main sett active holes did not vary between these three months and the rest of the survey period, either overall ($F_{(1,292)} = 0.13$, n.s.), or when considered by land class group ($F_{(1,292)} = 1.15$, n.s). The same was true for the 1990s main sett data ($F_{(1,393)} = 0.02$, n.s, and $F_{(1,393)} = 0.30$, n.s. respectively).

5.3.4 Group size and latrine use

The number of fresh droppings at latrines was demonstrated to be on the boundary or within the territory of the badger groups were related to group size. There was a significant, linear relationship between them ($r = 0.83$, $p<0.05$). When those fresh droppings in latrines with credit rating "2" were included (which were a small overall proportion), the correlation was not improved ($r = 0.80$, $p<0.05$).

5.3.5 Relationship between group size and sett size / latrine use combination

Multiple linear regression was used to determine how much of the variability in badger group size could be explained by a variate combining main sett active holes and fresh droppings within the territory. Main sett active holes was shown to explain 64% of the variation in group size for the 33 groups where such data were available (section 5.3.2). When the nine groups where group size, hole size and latrine data were all available were considered, the relationship was similar with 66% of the variation in group size explained ($r = 0.81$, $p < 0.01$) by main sett active holes. When fresh droppings within the territory were included, the resulting model explained 94% of the variation in group size ($r = 0.97$, $F_{(2,9)} =$ $p < 0.01$), which was a significant improvement on the model with only main sett active holes included ($F_{(1,6)} = 14.2$, $p < 0.05$). The model equation was:

Group size = 0.29 x *Active Holes* + 0.10 x *Fresh Droppings* - 0.10

The distribution of the dependent variable, group size, did not vary significantly from normal (Shapiro-Wilks = 0.86, n.s.). The residuals from the regression incorporating both variables were also not significantly different from normal (Shapiro-Wilks = 0.95, n.s.). Main sett active holes and fresh droppings were related to each other as might be expected, but the correlation was not significant ($r = 0.62$, n.s.) and the two variables met the required tolerance requirements such that they could both be included in the model together. Therefore, the assumptions for multiple linear regression were met.

5.4 Discussion

5.4.1 Relationships with social group size

Of the variables relating to sett numbers and activity collated in this pilot study, the number of active entrance holes at main setts proved to be the single best predictor of group size. The fact that total number of holes, of any level of use, at the main sett did not correlate with group size is not surprising, given that a number of factors will have an influence in determining this. Age of the sett, soil type, aspect etc. all have an influence, irrespective of the number of resident badgers (Neal & Roper, 1991). However, for any given badger main sett, it may expected that over time the number of actively used entrances will vary to some extent with variations in the number of resident badgers. Data from excavated setts (Roper, 1992a) showed that nest chambers within main setts are scattered throughout the extent of the sett, and are constructed in such a manner as to suggest that they could only be used by a small number of adults at any one time. It was also found during radio-telemetry studies that animals most frequently slept alone or in very small groups, except perhaps in winter (Roper, 1992b). If this remained the case with increasing group sizes then it would not be unreasonable to suggest that more entrances would be used regularly. The size of the sett, and eventual maximum number of entrance holes may be restricted by local geology and habitat, but this limit will vary with each individual sett. The theory that the observed increase in actively used entrance holes per main sett reflects an increase in group size is therefore supported.

It has been suggested that increased within-sett movement by badgers may restrict the build-up of ectoparasites such as fleas and ticks with which they and their nest are often infested (Hancox, 1980; Butler & Roper, 1996). It is also thought possible that there is a degree of competition among the female members of a social group for the opportunity to breed (Kruuk 1978b; Cheeseman *et al.* 1981). Therefore, there may be reproductive gains to be had by less dominant females in living in a separate part of the sett, again possibly resulting in more well-used entrances. In view of this, the fact that there was a significant relationship between group size and number of main sett active holes is not surprising. The variablility around the main regression trend, however, is a reflection of the independent influence on the number of holes of unrecorded parameters such as substrate type and available excavation area, and indeed variability in the behaviour of individual badger groups. It is entirely possible that if a large enough sample of badger groups were studied in different soil types, there would be closer, but differing relationships between group size and active hole counts within each soil type.

It was also unsurprising that the absolute number of setts in a territory was uncorrelated with group size. This parameter is more likely to be a factor of the availability of suitable sites than solely animal numbers, making the relationship a complex one. It might be expected, however, that number of very actively used outliers at any one time should give some crude indication of group size, given outlier sett site availability. More data, gathered from areas invariant in terms of substrate and sett site availability would be required to test this. In this pilot study, failure to count social group members located in outlier setts is the most likely source of error. Efforts were made to minimise this (section 5.2), but if indeed there was some under-recording of badgers at outlying setts, then the chances of a significant relationship with outlying setts would be reduced. Outlier sett use is very variable between both groups and individuals, and season. In one study, the overall frequency of outlier (defined as setts which were not 'main') sett use, averaged over five individuals in one social group, from September through until April, was 26% of days (Roper & Christian, 1992). Thus, count errors due to individuals sleeping in other setts are likely to be small.

5.4.2 Estimation of badger population size from main sett active hole data

Because group size was found to be meaningfully related to main sett active holes, such data held on the national survey databases for the 1980s and 1990s were incorporated. The relationship was used to produce an estimate of badger group size at each main sett, and thence a properly weighted average group size per land class group. The residual variation around the regression line meant there was a range of possible group size values (95% confidence) at each main sett, and therefore around the national population estimates. This range was relatively large. Within any given land class group, the relationship between main sett active holes and group size may possibly be slightly different and fit better than the overall regression presented here. A larger sample would be required to test this. However it is known that the soil conditions at a very local scale are the important factor in determining presence, and indeed size to some extent, of any given main sett (Dunwell & Killingly, 1969; Clements *et al.*, 1988) and so the land classification of a whole 1-km square is unlikely to be an influential factor and the relationship may not improve.

The resulting estimates indicated a badger population of just under 200,000 in the 1980s increasing to just over 300,000 in the 1990s: a population increase in Britain of around 60%. The overall mean group size was estimated to be approximately 4.8 in the 1980s and 6.1 in the 1990s, an increase of 27% on average. Although the value for the change in overall badger numbers is in broad agreement with the 75% increase estimated using the relative abundance method described in Chapter four, it is somewhat smaller. One possible reason for this is as mentioned earlier: it is possible that there was an element of underestimation of social group size. Watches at setts are prone to such error (Macdonald, Mace & Rushton, 1998) and it is intuitively obvious that larger social groups, which are more likely to be spread throughout the territory, will be underestimated more often. If this scenario is true, then using this method, the values for social group size, and therefore overall population size, are likely to be underestimated to a greater extent in the 1990s, due to the larger group sizes on average. The estimate of population change presented here would, under this scenario, be larger and hence closer to that estimated in Chapter four. Further research is required, with data from social groups for which the number of adults is known with absolute confidence, to test if this is indeed true. However, the findings here support those in Chapter four that there has been a considerable increase in social group sizes across much of Britain, in addition to the increase in numbers of social groups.

5.4.3 Prediction of group size using combined field sign variables

The good correlation between number of fresh droppings and group size suggested firstly that the estimates of group size were robust. Assuming that there is a consistent relationship between the two, the existence of residual variability around it can be explained in a number of possible ways: variable accuracy of group size estimates; not all latrines in the territory were found; inter-group variability in the intensity of feacal depositions throughout the territory. Any of these could apply in this study. One other likely reason explaining some of the error is the technique of counting all droppings in the latrine as being associated with the group in question. Boundary latrines are often shared by more than one group, with dung from badgers of neighbouring groups present in the latrines at any one time (Kruuk, 1978; Cheeseman *et al.*, 1981; Roper *et al.*, 1993). So the number of fresh droppings counted for any group in this study is likely to be an overestimate, to a greater or lesser extent depending on the proportion of latrines lying on the boundary, and the degree of contiguity between the territories of neighbouring groups. The strength of the correlation between fresh dung and group size suggests that this error was not great overall. Using main sett active holes and latrines in a combined variate, however, produced significantly better predictions of group size for this dataset than either main sett active holes or fresh droppings alone. They appear to be complementary in this respect. The amount of variation in group size described was impressively high. The reasons for this are unclear, but much of the variability in group size not accounted for by variations in main sett active hole numbers is thence explained by the number of fresh dung depositions. For example, a large social group may not be reflected in the number of active holes, for the reasons already discussed, but this may be compensated for by there being a large number of fresh droppings within the territory. However, it must be borne in mind that there were only nine groups included in this process. The true predictive power of the resultant model can only be assessed when tested against another, comparable dataset, which is not yet available. If this did prove to be an accurate technique for estimating badger abundance at a local scale, there would still be drawbacks to be overcome when applying it to field studies. The initial step of territory boundary delineation by baitmarking is labour intensive, particularly so if the area under investigation contains a number of badger social groups. There are, however, new methods being developed to approximate the territory boundary simply from the spatial distribution of main setts, using diamond-seeded tesselations (Stewart *et al.,* 1997). In this current study, the predictive model, including main sett active holes and active latrines, appeared to be robust to the relatively crude allocation of fresh dung in boundary latrines to the study group. Therefore a field methodology combining remote territory approximation, latrine survey and main sett survey (incorporating perhaps also soil type at main sett) could provide a quick and accurate means of estimating badger abundance at a local scale.

5.5 Summary

Active entrance holes into main setts were found to be correlated with group size. No other sett parameter within the territories was found to correlate more strongly. This relationship facilitated the estimation of an average social group size in each land class group, using the national survey data for the 1980s and 1990s. These were properly weighted for the typical variability in group size in these groupings. The population estimate in the 1980s, using this method was found to be 193,387 ± 37,031 adult badgers, and in the 1990s, 308,892 ± 47,376. This represented a badger population increase of around 60% in Britain between the two surveys, which was comparable to the result using the relative abundance method incorporating activity indices, as described in Chapter four. Number of fresh droppings within the territory of a given group was found also to correlate with group size. A multiple linear regression model incorporating both main sett active holes and fresh dung depositions was found to accurately predict group size, for the groups for which all these data were available. This model requires testing against another, comparable dataset. It is considered possible that a field method incorporating these techniques could be used in the future as a quick, easy method to estimate badger abundance accurately at a local scale. In Chapters six and seven, changes in habitat availability and levels of persecution will investigated to elucidate the reasons for the large increase in badger numbers between the surveys.

6. Habitat selection by badgers: the effect of changing landscape on badger distribution and abundance

6.1 Introduction

As with any animal species, a badger population can persist only where there is available habitat which is sufficiently productive in terms of food resource, and where there are suitable sites in which to live. Studies of badger diet have shown that they are true omnivores, being able to feed on a wide range of plant and animal material (Neal & Cheeseman, 1996). This gives them the theoretical capacity to thrive in a broad range of landscapes. Despite this catholic taste, however, badgers have been shown to rely heavily on certain foods. The earthworm *Lumbricus terrestris* has been shown to make up the majority of the diet in Britain. Hancox (1973) showed that earthworms occurred in 91% of over 2000 badger faeces from Wytham Woods near Oxford, making up 61% of the total volume. Kruuk (1978a) found that earthworms were the only food item found in consistently large quantities in scats, with wheat the next most abundant. He estimated that one 10 kg badger should need about 169 worms per day for its basic energy metabolism. Clearly, sufficient biomass of worms is required to support a badger population. Earthworms are found in greatest abundance in short grass pasture (Kruuk *et al.*, 1979); therefore, grassland habitat is considered important to badgers.

The badger's habit of living in groups, situated in large setts with extensive tunnel systems also has a bearing on its distribution. The reasons for expending such energies on constructing these elaborate living quarters have been the subject of some speculation. A variety of reasons for the evolution of this behaviour have been proposed: provision of a constant temperature /

environment; protection from predators; ventilation have all been suggested as reasons for the maintenance of these structures (Roper & Kemenes, 1997). Setts are situated in many different habitats, such as woodland, hedgerows, scrub, quarries, sea cliffs and many others (Neal, 1972). There are, however, certain factors which influence the choice of sett situation. In the Mammal Society National Badger Sett survey carried out from the 1960s, 81% of all setts recorded were situated in habitats which provide cover, such as woodland and scrub. Setts were dug into sloping land in 88% of cases, which facilitates removal of excavated soil, and tends to be well drained. In a survey of setts in Sussex, where 1,719 setts were recorded (Clements, 1974), 90% of them were in chalk or sandy soils. The combination of these requirements led Roper (1993) to suggest that suitable sites for the situation of badger main setts were limited. Badger distribution would be expected to reflect the availability of both of food resources and sett sites. To investigate this, habitat data collected in the 1980s and 1990s national badger surveys were investigated with respect to badger sett distribution.

Since the 1980s badger survey, there have been substantial landscape changes in Britain, and these have been summarised by Barr *et al.* (1993). Some of the key changes are listed in (Table 6.1); the definitions of the habitat types used by Barr *et al.* (1993) are broadly similar to those used in the badger survey. Most of the large changes were due to shifts between the major agricultural categories, principally tilled land and managed grass. The built-up category expanded, whereas managed grass and tilled land both declined in abundance. Broadleaved woodlands changed little in abundance overall. Conifer forests expanded in area, while the area of land covered in bracken declined. Within tilled land, for instance, there were increases in non-traditional crops, such as maize, which increased three-fold.

Table 6.1 Summary of some of the main changes in land-use in Britain, 1988-1997. ***(After Barr et al., 1993)***

Land cover type	Percent change
Broadleaved / mixed woodland	1
Coniferous woodland	5
Dense bracken	-11
Rough grass / marshland	45
Managed grass	-2
Tilled land	-4
Railways and roads	1
Built up	4

More substantial changes occurred in the linear features. Barr, Gillespie & Howard (1994) showed that in England and Wales, the length of hedgerows declined from 563,100 kilometres in 1984 to 431,800 kilometres in 1990 (77%), and that by 1993 this had declined further to 377,500 kilometres (67%), an annual loss of 20,600 kilometres of hedgerow. Thus, overall the increases in land cover between the two badger surveys (coniferous woodland, railways and roads, and built up) are mainly habitats not favoured by badgers. All the losses (hedgerows, dense bracken and managed grass), however, were habitat features favoured by badgers. Thus, if habitat availability was the most important factor determining the density and distribution of badgers in Britain, the habitat changes in the period between the two surveys would not be expected to lead to an increase in badgers. In this Chapter, the importance of habitat in determining badger distribution and density in Britain is investigated, and whether changes in habitat availability has led to the observed changes in badger numbers.

6.2 Methods

6.2.1 Data collection

Badger sett data were collected as described in Chapter two. Habitat data were also collected for each 1-km square surveyed. Details were recorded on Ordnance survey 1:25,000 Pathfinder maps, enlarged to approximately 1:6250. A habitat key was used to classify each parcel of habitat within the 1-km square (Appendix 11.3). Only linear habitats at least 50m in length, or habitats with an area of at least 0.5ha were recorded. The categories used were easy to identify, while at the same time related to the Nature Conservancy Council's National Vegetation Classification scheme (Rodwell, 1990). The data received from volunteer surveyors were checked for improbable categories, and for uniformity with my own. The 1-km squares were classified according to quality, as described in section 2.6. Upon completion of the 1-km squares, the areas of each habitat (and lengths of linear habitats) were measured using a computerised bit-pad.

6.2.2 Data analysis

Multivariate statistics were used to establish the importance of different habitat types, and combinations of habitats. Discriminant analysis was used to highlight those habitats which occurred in greater abundance in those squares with badger presence than those without. The habitat types which had greatest influence over the probability of badgers being present in a 1-km square were isolated via logistic regression. The analyses were confined to the 2169 1-km squares for which there were full habitat data for both surveys. Analyses were carried out for the country as a whole, and by land class and by region where appropriate.

6.3 Results

6.3.1 Correlations between habitats and main setts

As a first step in establishing which of the habitat variables recorded in the surveys were important in determining badger presence, simple bivariate correlations were carried out for each variable against main sett number. This determines, for the sample 1-km squares, whether differences in the area/length of a given habitat are reflected in corresponding changes in badger social group numbers. All habitat variables (Appendix 11.3) recorded were used in the analysis, and initially, no division was made into land class or regional groupings. The analysis was carried out for both the 1980s and 1990s data. The results are shown in Table 6.2 . Main setts in the 1980s were significantly positively correlated with semi-natural broadleaved woodland, the three commonly found lowland grassland types, hedgerows and tall scrub. Main setts were significantly negatively correlated with built land, drainage ditches, upland unimproved grassland and heather moor. The results were broadly similar in the 1990s, with the addition of arable land, mixed plantation, mixed woodland, low scrub and treelines. The results from these straightforward tests can be interpreted satisfactorily in terms of badger biology. The positively correlating factors are typically utilised by badgers as sett (cover) and foraging habitat (grassland). Conversely, the negatively correlating factors (built land, drainage ditches, upland grassland and heather moor) are all associated with habitats unsuitable for badgers, such as urbanised areas, low-lying wet areas and montane habitat. On a national scale, these are the features in terms of land- use / habitat type which are related to the persistence or otherwise of a badger population in or near any given 1-km square.

Table 6.2 Habitats with significant correlations with main setts (p < 0.01) in 1980s, 1990s or both. "-" denotes no significant relationship

Habitat	Direction of relationship 1980s	Direction of relationship 1990s
Semi-natural broadleaved woodland	positive	positive
Mixed plantation	-	positive
Mixed woodland	-	positive
Conifer plantation	negative	negative
Built land	negative	negative
Coastal sloping cliff	negative	-
Drainage ditch	negative	-
Treeline	-	positive
Hedgerows	positive	positive
Heather moor	negative	negative
Improved grassland	positive	positive
Semi-improved grassland	positive	positive
lowland unimproved grassland	positive	positive
Upland unimproved grassland	negative	negative
Arable	-	positive
Low scrub	-	positive
Tall scrub	positive	positive

6.3.2 Discriminant analysis to highlight potentially important variables

In the above analysis, none of the variables displayed a strong, linear correlation with main sett number. For example, the variable which correlated most strongly with main sett number in the 1980s was 'hedgerow', where $r = 0.17$. Therefore, it is clear that in the 1-km squares sampled in the national survey, little of the observed variation in main sett numbers was explained by the abundance of any single habitat variable. In view of this, multivariate methods were investigated to assess the importance of habitat combinations.

Use of discriminant analysis for predictive purposes was not viable due to sensitivity to non-normality of the independent variables. However, as a first step in the process, SPSS provides an output displaying the mean values for the independent variables in the different groups (e.g. 1-km squares with sett presence or 1-km squares with sett absence), and a one-way ANOVA test of significance of the difference between them.Table 6.3 shows those habitat variables which were significantly different between 1-km squares with and without main setts, in either the 1980s, 1990s or both.

Table 6.3 Habitats with significant differences ($p < 0.01$) in area / length between 1-km squares with and without main setts. Figures are given hectares, except where denoted otherwise. "-" denotes no significant difference.

	1980s		1990s	
Habitat Type	Average Area, Group Absence	Average Area, Group Presence	Average Area, Group Absence	Average Area, Group Presence
Arable	26.9	31.3	-	-
Blanket bog	2.5	0.2	2.5	0.1
Semi-natural broadleaved woodland	3.6	6.4	2.5	5.4
Mixed plantation	-	-	0.5	1.1
Mixed woodland	-	-	0.8	1.5
Conifer plantation	5.0	3.4	4.9	2.7
Drainage ditch (m)	407	245	-	-
Hedgerow (m)	2243	3835	1786	4097
Treeline (m)	475	648	384	694
Improved grassland	-	-	11.8	19.2
Lowland unimproved grassland	1.4	2.6	-	-
Semi-improved grassland	9.4	12.7	8.7	13.5
Upland unimproved grassland	7.5	2.2	5.0	1.8
Tall scrub	0.2	0.7	0.2	0.5
Low scrub	0.5	1.0	-	-
Heather moorland	6.0	0.5	5.3	0.5

The variables which were significantly different in abundance between 1-km squares with and squares without main setts are broadly the same as those which correlated significantly with main sett number (Table 6.2).

Table 6.4 Habitat variables with significant differences between those 1-km squares with main setts and those 1-km squares without, in the 1980s. Figures are in hectares, unless otherwise indicated

Land class group	I		II		III		IV		V		VI	
main sett / Habitat	absent	present	absent	present	absent	present	absent	present	absent	present	present	absent
Semi-natural broadleaved woodland	5.7	8.8							3.4	6.8	2.35	5.5
Broadleaved plantation											0.13	0.54
Conifer plantation	1.3	4.6	0.9	2.0								
Semi-improved grassland	4.2	9.3							14.3	23.5		
Improved grassland			8.6	15.5			19.2	28.2				
Treeline (m)					380	934					319	992
Hedgerow (m)			3169	4487			3857	4892			813	1933
Drainage ditch (m)			1080	461								
Built-up land							12.7	6.6	11.7	5.8		
Tall scrub	0.3	1.1					0.3	0.7				
Low scrub											0.37	1.05

Table 6.5 Habitat variables with significant differences between those 1-km squares with main setts and those without, in the 1990s. Figures are in hectares, unless otherwise indicated

Land class group	I		II		III		IV		V		VI	
Habitat \ Main sett	absent	present	absent	present	absent	present	absent	present	absent	present	present	absent
Semi-natural broadleaved woodland			2.9	5.12			2.6	4.5			1.8	5.5
Broadleaved plantation							0.27	0.75				
Conifer woodland												
Mixed plantation	0.9	3.7									0.3	1.4
Improved grassland			6.9	14.7			15.5	23.4				
Semi-improved grassland	4.1	11.1			6.7	16.1					11.4	18.6
Treeline (m)			476	863			401	719	470	815		
Hedgerow (m)			2475	3572			2863	5620			741	2464
Arable			54.9	51.5			18.5	25.3	29.3	27.6		
Built-up land							12.9	8.3				

The same procedure was carried out within land class groups, and the results, for the 1980s and 1990s respectively are given in Table 6.4 and Table 6.5. There are fewer significant variables overall in each of the land class groups in the 1990s, but there is much similarity in the habitats which were more or less abundant in 1-km squares containing badger social groups.

6.3.3 Logistic regression to investigate nationally influential habitat combinations

As mentioned above, discriminant analysis is known to be very sensitive to violations of the assumptions of multivariate normality. When this is the case, as with the badger survey data, it is advised that any results obtained from a discriminant analysis be verified by using a parallel technique (Hair *et al.* 1995). When dealing with a two category dependent variable, as with presence / absence data, the alternative technique usually employed is logistic regression. Logistic regression analysis is far less sensitive to deviations from normality in the independent variables than discriminant analysis.

Logistic regression is a form of Generalised Linear Modelling, where the probability of an event occurring (badger sett presence) is modelled given the various inter-relations with the independent variables. As a first step, presence or absence of badger main setts was used as the predicted variable, with the recorded habitat variables acting as the independent values.

The variables were always entered simultaneously into the model. This method of variable selection is considered more statistically robust than forward selection or backward elimination when a large number of independent variables are under investigation. The analysis was initially run on the data for the whole country. The model produced in this way performed poorly, predicting correctly the presence of badger main setts only 9% of the time, which was less than would have been expected purely by chance, in the 1990s (21%); 1-km squares tended to be overclassified into the 'absent' category.

This poor performance can be explained by the nature of the data. The 1-km squares sampled in the badger survey were distributed across the whole of mainland Britain. Although the analyses in sections 6.3.1 and 6.3.2 highlighted variables which exist in greater abundance in 1-km squares containing main setts, none of them correlated strongly with main sett number. Similarly, when taking the country as a whole from a multivariate point of view, it is not possible to select a single combination of habitat variables - a variate - which will predict with accuracy badger main sett presence. This is because in different geographical areas / regions of the mainland, habitats have differential influence in terms of badger population persistence i.e. a habitat which is important in one area may not be in another. Also, the underlying distribution of badger social groups may have an effect. Badgers are known to display a clumped distribution in terms of main setts, therefore there are many 1-km squares which do not contain badgers irrespective of the habitat which comprises them. A 1-km square can be considered a small area of survey when the territory size of an average badger group is taken into account. Due to the spacing of badger groups, and their clumped nature, for any given sample square there remains a relatively high chance of a badger group or groups existing just outside the square, irrespective of the habitat within it. Therefore, logistic regression analysis was carried out on the presence or absence of any sett, rather than main setts alone, as an indicator of badger presence. In the 1990s, 33% of 1-km squares contained a sett of any type, as opposed to 21% which contained main setts, and so the technique would be expected to be more successful.

When applied to the whole country, the model in this case performed considerably better than when considering main setts alone, and 40% of the 1-km squares which contained a sett were correctly predicted as such, compared to a prior probability of 33%. However, the ability of the recorded habitat variables to predict the presence or absence of badger setts on a country-wide basis remains limited.

6.3.4 Logistic regression to investigate influential habitat combinations within land class groups

As described in section 2.2, 1-km squares with the same land class grouping have similar underlying characteristics in terms of land-use, climate, geology etc. It is reasonable to surmise, therefore, that variations in badger numbers (as represented by sett numbers) will be modelled with greater accuracy within the relatively less variable strata provided by the land class groups. Logistic regression analyses as described above were performed on each of the land class groups. Upland VII is ommitted from the following analyses, because the very small number of setts contained therein means such analysis is inappropriate due to the high probability of spurious results.

Table 6.6 Significant variables from logistic regression, by land class group in the 1980s (*= p<0.05, **=p<0.01, ***=p<0.001).

Land class group I		Land class group II		Land class group III		Land class group IV		Land class group V		Land class group VI	
Habitat	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**
LSB	0.11*	BLW	0.07*	RESV	1.67*	IMG	0.11**	TRE	0.14**	BLW	0.15**
SIG	0.08*	HDG	0.06*	TSB	0.11*	BLW	0.10**	TSB	0.06*	HDG	0.11*
CP	0.06*	TSB	0.03*	BLP	0.10*	RIV	0.07*	BLP	0.05*	LSB	0.09*
BLW	0.05*			MP	0.09*	ABL	0.06*			LUG	-0.07*
						TSB	0.05*				
						HDG	0.05*				

Table 6.7 Significant variables from logistic regression, by land class group in the 1990s (*= p<0.05, **=p<0.01, ***=p<0.001).

Land class group I		Land class group II		Land class group III		Land class group IV		Land class group V		Land class group VI	
Habitat	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**	**Habitat**	**R**
SIG	0.14**	BLW	0.15***	HDG	0.18**	HDG	0.15***	BLW	0.21***	BLW	0.14***
HDG	0.12*	HDG	0.10**	LUG	0.15*	BUL	-0.05*	HDG	0.17**	HDG	0.12*
TRE	0.09*	TRE	0.08*	BKN	0.14*	BLW	0.05*	TRE	0.13**	LSB	0.04*
		SIG	0.05*	BUL	-0.13*						
				TSB	0.11*						

KEY: BLW=semi-nat. broadleaved wood., BLP=broadleaved plantation, CP=conifer planation, MP=mixed plantation, SIG=semi-improved grassland, IMG=improved grassland, LUG=lowland unimproved grassland, TSB=tall scrub, LSB=low scrub, BKN=bracken, HDG=hedge, TRE=treeline, ABL=arable, BUL=built land.

The variables which influenced significantly the probability of setts being present in any given square are shown in Table 6.6 and Table 6.7. The R-statistic presented in the tables describes the partial correlation, between the habitat variables and the probability of sett presence, taking into account the contribution of the other variables. The larger the value, the greater the probability of an event occurring, and the greater influence that variable has. A minus sign indicates a negative correlation. The habitats are listed in order of magnitude of influence. Model fit was assessed by comparing predictions from the model with prior probability. Model fit for each land class group in the 1980s and 1990s are presented in Table 6.8 and Table 6.9.

Logistic regression modelling performed with variable accuracy within each of the different land class groups. The models predicted the presence of setts considerably better than the prior probability in all groups in both surveys, except in land class group II. The variables with the greatest influence on the probability of a sett being present varied from group to group, but there were a number of habitat types which appeared to be important across most of the land class groups. Semi-natural broadleaved woodland and hedgerow appeared most often as significant variables. Scrub (low and tall) also featured consistently, and grassland was occasionally a significant variable (improved, semi-improved or lowland unimproved). Habitat factors associated with providing cover were most often the most influential variable and have the greatest influence in determining the probability of badgers being present in any given square, when the effect of the other habitat variables is taken into account.

Table 6.8 Model fit of logistic regression using habitat variables to predict presence or absence of badger setts, 1980s.

Land class group	Percent 1-km squares correctly predicted to contain setts	Percent prior probability of setts being present	Percent 1-km squares correctly classified overall
Arable I	78	55	70
Arable II	28	26	76
Arable III	36	15	87
Pastoral IV	73	49	69
Pastoral V	29	30	73
Marginal upland VI	31	17	86

Table 6.9 Model fit of logistic regression using habitat variables to predict presence or absence of badger setts, 1990s.

Land class group	Percent 1-km squares correctly predicted to contain setts	Percent prior probability of setts being present	Percent 1-km squares correctly classified overall
Arable I	80	55	73
Arable II	32	32	72
Arable III	37	15	89
Pastoral IV	76	55	71
Pastoral V	49	36	74
Marginal upland VI	31	21	85

6.3.5 Habitats favoured as sites for main setts

In order to investigate the importance of habitat as sites for sett location, the habitats were grouped into functionally similar groupings. This is because some of the habitats are very similar in character, and there is a degree of subjectivity in the divisions between them. For example, in the case of the lowland grassland types (unimproved, semi-improved, improved), they are characterised by the degree of management, past and present, but with respect to badger sett selection, are similar in physical and biological terms. The groupings used are outlined below:

hedgerows - hedgerows; *treelines* - treelines; *broadleaved woodland* - semi-natural broadleaved woodland, broadleaved plantations, young plantations; *coniferous woodland* - semi-natural coniferous woodland, coniferous plantations; *mixed woodland* - semi-natural mixed woodland, mixed plantations; *parkland* - parkland; *scrub* - tall scrub, low scrub; *bracken* - bracken; *lowland heath* - lowland heaths; *upland* - heather moorlands, blanket bog, upland unimproved grassland; *grassland* - lowland unimproved grassland, semi-improved grassland, improved grassland; *arable* - arable; *cliffs* - unquarried inland cliffs, vertical coastal cliffs, sloping coastal cliffs; *quarries and mines* - quarries and open-cast mines; *built land* - built land, amenity grassland; *other* - all the other habitat types listed in Appendix 11.3. The number of main setts in each habitat group was then explored.

Across all land class groups except Arable III, broadleaved woodland was the most regularly selected habitat for main sett sites, followed by hedgerows. In the Arable III land class group, coniferous woodland was more important. Since there were generally few differences between land class groups, these were combined to present the overall changes between the two surveys (Table 6.10). Broadleaved woodland and hedgerows were selected most regularly for main sett location. Grassland was also commonly used. Coniferous and mixed woodland, scrub and bracken were also regularly used. Therefore habitats which are associated with providing cover are preferentially selected as sites for main setts.

Table 6.10 The percent of main setts recorded in each habitat group across all land class groups in the 1980s and 1990s.

Habitat	1980s	1990s
Broadleaved woodland	35	34
Hedgerows	15	16
Grassland	11	8
Coniferous woodland	8	6
Scrub	8	7
Mixed woodland	6	10
Bracken	3	2
Arable	3	4
Quarries and mines	3	2
Treelines	3	6
Upland	1	1
Cliffs	1	1
Parkland	0	1
Built Land	0	1
Other	0	1

6.3.6 Changes in availability of important habitat types, from the 1980s to the 1990s

Changes in average area and length of the important habitat types, as defined from the analyses in sections 6.3.2, 6.3.4 and 6.3.5 were calculated for each land class group (Table 6.11). There were no major changes in the average availability of the different habitats overall, but there were variations between the two surveys. The average length of linear features (hedgerow and treeline) declined over much of the country. There was little change overall in abundance of cover-providing habitats (broadleaved and coniferous woodlands, and scrub types) although there was a slight decline in average availability of semi-natural broadleaved woodland in much of the country. Noteably, broadleaved woodland, the single most important habitat type, declined slightly on average in the land class groups which exhibited the largest increases in badger social group numbers (II, VI, V and VI). Across the land class groups, semi-improved and improved grassland appeared to mirror each others declines or increases, but combined there was little change in their abundance. There was a tendency for an increase in area of unimproved grassland, which would not be considered specifically beneficial to badgers.

6.3.7 Changes in availability of optimal 1-km squares.

Linear modelling procedures such as logistic regression uses abundance, as measured in area or lengths, of the independent variables to estimate a relationship with the dependent variable. Simple bivariate correlations showed that on a square by square basis, no habitat type recorded in the surveys correlated strongly with badger social group numbers. An alternative approach is to define a 'good' square for badgers by considering simply the presence or absence of habitat combinations rather than their relative magnitudes. Reason, Harris & Cresswell (1993) used the data from the 1980s badger survey to achieve this. Using the habitat features which were important in terms of sett site location, and those which were significantly more abundant in 1-km squares with badgers present, it was found that the most successful combination of features for defining a 'good' square for badgers was a square with five or more of the following: hedgerows, treelines, semi-natural broadleaved woodlands, semi-natural mixed woodlands, mixed plantations, parkland, tall scrub, low scrub, bracken, running natural water, lowland unimproved grassland, semi-improved grassland, and improved grassland. The availability of 1-km squares with five or more favoured habitat types declined by 19% overall in the nine years between the two surveys. This trend was not uniform across the country. The magnitude of the decline varied between the land class groups (Table 6.12) and even more so when considered on a regional basis (Table 6.13). In some regions the declines were small, and there were even small increases in the availability of "good" 1-km squares in two regions.

Table 6.11 Changes in the availability of important habitats between the 1980s and 1990s surveys. Figures are average per 1-km square; hedgerows and treelines are given in metres, all other habitats types are in hectares

	Arable I		Arable II		Arable III		Pastoral IV		Pastoral V		Marginal upland VI	
	1980s	1990s	1980s	1990s	1980s	1990s	1980s	1990s	1980s	1990s	1980s	1990s
Specific habitats												
Hedgerows	3040	3680	3750	3260	1500	1190	4860	4530	4320	3980	980	910
Treelines	610	560	620	550	420	330	530	520	650	540	370	340
Totals	**3650**	**4250**	**4370**	**3810**	**1920**	**1520**	**5390**	**5050**	**4970**	**4520**	**1350**	**1250**
Semi-natural broadleaved woodland	6.7	6.2	3.4	3.4	2.0	1.4	3.6	3.3	3.8	3.6	2.6	2.2
Broadleaved plantations	1.7	1.1	1.4	1.4	0.1	0.1	0.9	0.4	0.4	0.2	0.2	0.1
Coniferous plantations	2.5	1.8	1.0	0.8	6.6	6.5	1.4	1.0	3.9	4.0	8.6	8.7
Mixed plantations	1.3	1.9	0.3	0.4	0.7	1.0	0.3	0.5	0.5	0.6	0.0	0.4
Tall scrub	0.6	0.5	0.2	0.6	0.2	0.2	0.4	0.5	0.3	0.3	0.1	0.2
Bracken	0.1	0.1	0.1	0.1	0.3	0.2	0.7	0.7	0.4	0.5	3.3	3.0
Low scrub	0.6	0.5	0.4	0.3	0.7	0.7	1.2	1.4	0.7	0.6	0.4	0.6
Totals	**15.7**	**15.0**	**7.4**	**7.3**	**11.1**	**11.0**	**8.0**	**8.1**	**10.2**	**9.9**	**12.5**	**13.7**
General habitats												
Lowland unimproved grassland	3.8	3.8	1.4	1.8	1.4	1.3	2.4	2.6	1.5	3.1	0.6	1.8
Semi-improved grassland	5.9	6.7	7.4	6.6	10.1	7.4	9.6	13.3	15.6	14.9	16.0	12.2
Improved grassland	10.6	9.0	9.5	8.5	12.6	16.8	21.7	18.5	22.0	21.5	10.4	16.0
Totals	**20.3**	**19.5**	**18.3**	**16.9**	**24.1**	**25.5**	**33.4**	**34.4**	**39.1**	**39.5**	**27.0**	**30.0**

Changes in sett numbers were then considered with respect to “good” and “poor” 1-km squares. The number of main setts in "good" 1-km squares increased between the two surveys. However, there was a greater increase in the number of main setts in "poor" 1-km squares, and overall the proportion of main setts in "good" 1-km squares declined by 6% (Table 6.14 and Table 6.15). In the 1990s, 65% of "good" 1-km squares still lacked a main sett, compared to 86% of "poor" 1-km squares. Thus, there were still many 1-km squares with good badger habitat which lacked a main sett.

6.3.8 Habitat richness to explain appearance or disappearance of main setts

Changes in the number of “good” and “poor” 1-km squares were compared to changes in the number of main setts on a regional basis. A Spearman rank correlation showed there was no significant correlation between regional changes in the number of main setts and the change in number of "good" 1-km squares (r_s=-0·27, n.s.). The number of favourable habitats present, as defined in section 6.3.7, were used to assign a ‘richness’ score to the sample 1-km squares. 1-km squares which contained main setts at the time of the 1980s survey were selected. 1-km squares which gained additional main setts between the two surveys had a mean richness score greater than 5·0, while 1-km squares which had lost main setts had a mean richness score of less than 5·0 (Table 6.16).

The 1-km squares which lost main setts tended to have lower habitat richness scores than those 1-km squares which gained mains setts.

Table 6.12 Changes in the availability of "good" 1-km squares for badgers between the two surveys by land class groups

Land class group	Number of 1-km squares surveyed	Number (percent) of "good" 1-km squares, 1980s	Number (percent) of "good" 1-km squares, 1990s	Percent change in the number of "good" squares
Arable I	198	96 (48)	57 (29)	-41
Arable II	467	189 (40)	155 (33)	-18
Arable III	185	67 (36)	46 (25)	-31
Pastoral IV	405	200 (49)	174 (43)	-13
Pastoral V	300	153 (51)	137 (46)	-10
Marginal upland VI	329	101 (31)	81 (25)	-20
Upland VII	285	16 (6)	12 (4)	-25
Totals	**2169**	**822 (38)**	**662 (31)**	**-19**

Table 6.13 Regional changes in the availability of "good" 1-km squares for badgers between the two surveys

Region	Number of 1-km squares surveyed	Number (percent) of "good" 1-km squares, 1980s	Number (percent) of "good" 1-km squares, 1990s	Percent change in the number of "good" squares
North England	162	55 (34)	47 (29)	-15
North-west England	69	37 (54)	31 (45)	-16
North-east England	116	36 (31)	23 (20)	-36
West Midlands	156	97 (62)	95 (61)	-2
East England	143	54 (38)	34 (24)	-37
Central England	83	38 (46)	39 (47)	3
East Anglia	158	43 (27)	38 (24)	-12
South-west England	200	111 (56)	88 (44)	-21
Southern England	123	65 (53)	35 (28)	-46
South-east England	145	58 (40)	47 (32)	-19
North Scotland	364	60 (16)	37 (10)	-38
South Scotland	205	60 (29)	45 (22)	-25
Mid & north Wales	138	58 (42)	61 (44)	5
South Wales	107	50 (47)	42 (39)	-16
Totals	**2169**	**822 (38)**	**662 (31)**	**-19**

Table 6.14 Change in the number of main setts in "good" and "poor" 1-km squares for badgers between the two surveys by land class groups

Land class group	Number of main setts in the 1980s	Number (percent) main setts in "good" 1-km squares in the 1980s	Number (percent) main setts in "poor" 1-km squares in the 1980s	Number of main setts in the 1990s	Number (percent) main setts in "good" 1-km squares in the 1990s	Number (percent) main setts in "poor" 1-km squares in the 1990s
Arable I	90	48 (53)	42 (47)	93	45 (48)	48 (52)
Arable II	84	52 (62)	32 (38)	109	51 (47)	58 (53)
Arable III	18	9 (50)	9 (50)	17	9 (53)	8 (47)
Pastoral IV	168	103 (61)	65 (39)	207	119 (57)	88 (43)
Pastoral V	53	36 (68)	17 (32)	73	46 (63)	27 (37)
Marginal upland VI	32	19 (59)	13 (41)	45	28 (62)	17 (38)
Upland VII	2	1 (50)	1 (50)	5	1 (20)	4 (80)
Totals	**447**	**268 (60)**	**179 (40)**	**549**	**299 (54)**	**250 (46)**

Table 6.15 Regional changes in the number of main setts in "good" and "poor" 1-km squares for badgers between the two surveys.

Region	Number of main setts in the 1980s	Number (percent) main setts in "good" 1-km squares in the 1980s	Number (percent) main setts in "poor" 1-km squares in the 1980s	Number of main setts in the 1990s	Number (percent) main setts in "good" 1-km squares in the 1990s	Number (percent) main setts in "poor" 1-km squares in the 1990s
North England	18	8 (44)	10 (56)	19	8 (42)	11 (58)
North-west England	13	8 (62)	5 (38)	12	8 (67)	4 (33)
North-East England	17	9 (53)	8 (47)	19	8 (42)	11 (58)
West Midlands	37	30 (81)	7 (19)	70	54 (77)	16 (23)
East Midlands	25	15 (60)	10 (40)	28	11 (39)	17 (61)
Central England	20	9 (45)	11 (55)	24	13 (54)	11 (46)
East Anglia	9	6 (67)	3 (33)	13	3 (23)	10 (77)
South-west England	115	77 (67)	38 (33)	141	81 (57)	60 (43)
Southern England	42	26 (62)	16 (38)	49	20 (41)	29 (59)
South-east England	50	24 (48)	26 (52)	57	26 (46)	31 (54)
North Scotland	8	6 (75)	2 (25)	12	4 (33)	8 (67)
South Scotland	15	6 (40)	9 (60)	15	12 (80)	3 (20)
Mid and North Wales	34	25 (74)	9 (26)	45	31 (69)	14 (31)
South Wales	44	19 (43)	25 (57)	45	20 (44)	25 (56)
Totals	**447**	**268 (60)**	**179 (40)**	**549**	**299 (54)**	**250 (46)**

Table 6.16 The mean habitat richness in 1-km squares for different patterns of change in main sett numbers

Pattern of change in main sett number, 1980s to 1990s	Sample size	Mean habitat richness, 1980s
Increased number of main setts, 1980s to 1990s (squares which already contained main setts in the 1980s)	41	5.4±0.2
Appearance of main setts in previously blank squares	150	5.0±0.1
No change	227	4.8±0.0
Decreased number of main setts in 1980s to 1990s	91	4.7±0.2
No main setts, 1980s or 1990s	1660	3.5±0.1

Habitat richness in those 1-km squares which gained main setts was significantly greater than in those 1-km squares where the number of main setts stayed the same (Mann-Whitney; z=-2·13, p<0·05). The habitat richness was not significantly different between 1-km squares which lost main setts and 1-km squares in which there were main setts in the 1980s and remained the same (Mann-Whitney; z=-0·39, n.s.). However, richness was significantly lower in those 1-km squares in which there were no main sett in both surveys, and those in which there were no main setts in the 1980s but subsequently gained main setts (Mann-Whitney; z=-9·20, p<0·0001).

6.4 Discussion

6.4.1 *Overview of the important habitat types*

A number of habitats were shown to be significantly different in terms of area or length in those survey 1-km squares in which badger social group(s) existed. When considering the whole country, 16 habitat variables were significantly different in either the 1980s, 1990s or both. Most of these were positively associated with the presence of badger main setts, the exceptions being area of blanket bog, upland unimproved grassland and conifer plantation which are all common to upland areas (primarily Upland VII) known to be scarcely populated by badgers. The habitats which were in abundance in 1-km squares harbouring badgers can be interpreted satisfactorily in terms of badger biology, providing cover or foraging.

When the sample was divided by land class group, the resulting patterns of differentiating variables were more complex. 1-km squares from any given land class group are by definition homogenous in certain underlying aspects of their physical and biological nature. Therefore, it is unsurprising that the variables which were important to badgers should vary between groups. In both the 1980s and 1990s, in each of the land class groups, there was commonly a combination of one or more of each of the cover and foraging factors which varied significantly between 1-km squares with and 1-km squares without badger social groups. There were, however, different combinations in the different land class groups, which again can be interpreted in view of the underlying nature of the groupings. In arable land class groups I, II and III, 1-km squares containing main setts had significantly more pasture (semi-improved or improved). These are groupings of 1-km squares comprised of primarily arable land, which is avoided by badgers (Cresswell *et al.*, 1990), and so presence of pasture in this landscape would be expected to be exploited preferentially by badgers. The same can be said for the higher average length of hedgerow in land class group II. Pastoral land class groups IV and V are groupings of 1-km squares which are the most heterogeneous in nature, having the greatest abundance of "good" 1-km squares. However, habitat factors providing cover and foraging, were still in greater abundance in 1-km squares with main setts. So despite the overall heterogeneous nature of the 1-km squares in the pastoral areas, badgers still tend to exist in areas where those habitats are in greater abundance. Built-up land was negatively associated with main setts, with badgers tending to exist in areas with less habitation.

In Marginal upland VI, cover in the form of woodland (broadleaved), treelines and hedgerows, appears to the most important factor, being significantly more abundant in 1-km squares with badgers. This is unsurprising in an upland landscape where the terrain is likely to be largely open, with relatively little cover. Therefore, the underlying landscape of an area affects to an extent which habitat types are likely to be favoured, or required in abundance, to maintain a badger population.

6.4.2 Influential habitat types

Habitat types which occur in greater abundance in 1-km squares with main setts are influential to different extents in predicting whether badgers will be present, when the other variables are taken into account. Badgers tend to exist in areas with an abundance of certain ecologically important habitat types. The logistic regression analysis highlighted a small number of habitats which were most influential in determining whether or not badgers would be present, when the relationship between badger presence and all the habitat variables were investigated simultaneously.

Overall, there was agreement to some extent in the habitats which differed significantly between 1-km squares with and without badger social groups, and the habitats which were most influential in terms of probability of badger presence. The overlap of results was not complete, however. The habitats found to have the greatest influence on the probability of badgers being present tended to be habitats associated solely with providing cover. Foraging habitats featured rarely. Broadleaved woodland and hedgerow were commonly the variables with the most influence. These same habitat types were also the most favoured sites for main sett location, and so although badgers tend to locate their main setts in areas with an abundance of both cover and foraging, cover availability has the greater influence in determining badger presence. The differences between the two surveys,for the same land class groups, in the habitats highlighted as being important is, at least in part, due to the lack of strong correlations between badger presence and abundance of the habitat types.

It has been suggested that suitable sites for main setts are a limiting resource, and are an important factor in determining population density (Roper, 1993). Of 18 environmental variables investigated by Thornton (1988) in relation to main sett distribution, tree cover was one of only three variables which correlated with sett density. The other two were concerned with substrate and aspect, neither of which were recorded in the national surveys. These studies support the results presented here: while badgers are more likely to exist in areas with sufficient cover and foraging, cover-providing factors are the most important. Clements *et al.* (1988) reported that 81% of badger setts were dug into sites associated with woodland, scrub or hedgerow, which are believed to be favoured due to the protection afforded to emerging badgers. The earlier work of Kruuk *et al.* (1979) showed that the primary food of badgers, earthworms, is especially common in short-grass pasture, and that the territory size of a social group is related to the distribution of food patches such as this. He proposed that badger density is defined primarily by food availability, in two steps:

1. Social group density, as determined by territory boundaries.

2. Group size, as determined by the productivity of the territory.

The results presented here suggest that although badgers do preferentially live in areas with abundance of prime foraging habitat, sett site availability provided by cover habitats is the more influential factor. This supports the work of Thornton (1988) and Roper (1993) who proposed that sett site availability determines main sett density directly, thereby dictating social group density, which, combined with social group size will determine badger density.

Soil type and slope are known to be important factors in determining where setts are dug. Certain substrates are conducive to digging and the majority of badger setts are dug into these. Thornton's analysis found substrate type to be significantly correlated with main sett density. Clements *et al.* (1988) recorded that 67% of main setts in Britain were dug in either sandy soil or in chalk. 92% were dug into sloping ground. These variables were not recorded in the surveys reported in this thesis, therefore by necessity were ignored in the analyses. Inclusion of these factors would obviously improve the predictive power of the logistic modelling process. However, even within these particular soil types, cover is important. In an area in the Chilterns, Dunwell and Killingly (1969) noted that setts were more abundant in upper chalk than in clay, and more numerous in woodland than in the open. However, further analysis showed that even within the chalk, there was a significant preference for woodland. This was also the case at Wytham, when even in the preferred soil, calcareous grit, woodland was preferred for main sett location.

Between the two surveys, there were no striking changes in habitat availability of the important habitat types which would have been expected to lead to an increase in badger numbers. If anything, the opposite trend would have been expected.

6.4.3 The effect of habitat richness

Habitat selection by badgers has not changed significantly between the two surveys, but the availability of "good" 1-km squares, as defined by heterogeneity of beneficial habitats for badgers, declined by 19%. In parallel with this, a higher proportion of badger social groups were found to be in "poor" 1-km squares in the 1990s than in the 1980s. This is partially due to 1-km squares which were borderline "good" in the 1980s losing that classification in the intervening period, but retaining badger presence. By definition, a 1-km square can in theory lose a "good" classification by losing perhaps one patch of bracken or scrub thus lowering the richness score to less than 5.0. This may not affect the badger population in the square in any way. In a case such as this, the square would still contain badgers despite being classed as "poor" in the 1990s.

Habitat richness did appear to be related to the patterns of main sett appearance and disappearance. In 1-km squares in which main setts increased in number or newly appeared, the habitat richness was higher than in those 1-km squares where there were no main setts in either survey, or where there was a decline in number. Thus, on average, the very good 1-km squares for badgers, into which they were most likely to expand, were less likely to be borderline "poor". Therefore, although habitat richness is not the sole determinant of badger presence in an area, it does influence changes in the badger population; the likelihood of an increase or decrease in the badger population in any given square is influenced by the habitat richness within it.

6.5 Summary

A number of habitat types recorded in the during the badger surveys of the 1980s and 1990s were shown to be important. Habitats primarily associated with cover (woodland, hedgerow, scrub) and foraging areas (pasture categories) were typically more abundant in squares containing badger social groups. Different habitat variable combinations displayed this pattern in the different land class groups. Logistic regression analysis highlighted variables which had significant influence on the probability badgers being present in any given 1-km square. These habitats were primarily those which provide cover, and were most commonly selected for sett site selection. Although an abundance of foraging area is preferred by badgers, overall, sett site availability would appear critical in determining the potential of a 1-km square to maintain a badger population.

In the face of a decline in the proportion of 1-km squares which would be considered good for badgers, the population has increased considerably. The robust nature, relative lack of habitat specificity, and adaptability of badgers undoubtedly plays a role in this, but it raises the question of what the factors are which have influenced the population increase. Habitat changes, at least at the scale recorded in the national surveys, were not the factor causing the badger population increase. Although not necessarily causative, habitat richness does appear to influence where the changes have occurred. The trend of declining habitat heterogeneity is of concern. Although the badger population has thrived during this period, there is no guarantee that this pattern will continue in the face of further degradation. Chapter seven investigates the changing levels of persecution, to ascertain if the tightening of badger protection legislation has led to the observed numerical response.

7. Changes in levels of persecution of badgers in Britain, 1988 to 1997

7.1 Introduction

In this thesis I have shown that in the nine years between the two national surveys, the badger population in Britain increased significantly. As explained in Chapter one, hitherto it had always been assumed that any changes in the badger population would be slow, and so this population recovery was an unexpected result. Analysis of the changes in land-use between the two surveys in the previous Chapter showed that there had been no trends that would have been likely to drive the population upwards. In fact, the changes in habitat availability would have been expected to have a detrimental effect on badger numbers. It is also unlikely that climatic factors would have caused this increase: weather in Britain is variable over short time scales, but if anything, the conditions showed a warmer, drier trend in much of the period between the two surveys. These are not considered ideal conditions for cub survival, and would not be considered a causative factor for the increase.

In this Chapter, recorded persecution levels are compared between the two surveys. In particular, those practices which leave visible signs, and which could be quantified from the survey results, are examined. These are signs of digging at setts, and also blocking. The potential for any observed changes in these factors to drive the population increase are discussed.

7.1.1 Changes in the badger protection laws

Persecution by farmers and gamekeepers, particularly last century, and more recently by badger diggers, is believed to have had a significant impact on badger numbers (Section 1.3). In recent years, and within the lifetime of this monitoring scheme, there have been considerable changes in the laws designed to protect badgers since the sett survey initiated by The Mammal Society, with a potential for a significant impact on badger populations. The first legal protection was given by the Badgers Act 1973. This provided some protection, but it still allowed badgers to be killed by authorised people with the landowners permission, and this included digging. The single most important piece of legislation protecting badgers was the Wildlife and Coutryside Act 1981. Badger digging was finally made illegal, as was the killing of badgers by the traditional means of snaring, gassing, trapping and shooting. Following the passing of this Act, badger control required appropriate licensing by the government. In 1991, badger setts were given legal protection by the Badgers Act 1991. This made it an offence to intentionally or recklessly damage, destroy or obstruct access to any part of badger sett, to cause a dog to enter a badger sett or to disturb a badger when it is occupying a sett. A separate Act, the Badgers (Further Protection) Act 1991, made provision for the removal, disposal or destruction of any dogs used illegally for badger digging. This Act made a number of exceptions and licensable procedures to facilitate activities such as foxhunting and gamekeeping. The various badger protection laws were brought together by the Protection of Badgers Act 1992.

Legal restrictions regarding the use of chemicals have also increased in recent years, and these should have benefited badger populations. In particular, under the Control of Pesticides Regulations 1986, Cymag only has approval for use against rabbits and rats and no product is currently approved for gassing foxes. Thus, the risk of badger setts being accidentally gassed during fox control operations should have been removed, although the "accidental" gassing of setts during rabbit control operations remains a risk. However, the annual reports by MAFF show that the number of reported incidents each year is very low. For instance, of 56 cases of suspected pesticide poisoning of badgers reported in 1994, only one was due to the abuse of cyanide (and only three others were confirmed as having died from the effects of pesticides) (Fletcher, Hunter & Barnett, 1995).

When the original badger survey was initiated, the Wildlife and Countryside Act had been in place for four years, and by the time the repeat survey was carried out the legislation protecting setts had been passed. Therefore, the resurvey described in this thesis provided an opportunity to determine whether the legislation had led to a reduction in the interference at badger setts.

Although illegal, other forms of persecution still occur. Hunting with lurchers, shooting at night with the aid of powerful lamps, illegal gassing or widespread snaring leave few field signs. Therefore the snapshot picture obtained from this survey could not quantify such activities. Thus, the results obtained represent a minimum estimate of the levels of selected types of persecution.

7.2 Results

In the 1980s, the levels of persecution at badger setts were high; Cresswell, Harris & Jefferies (1990) recorded digging at 10.5% of active main setts, with hole blocking at 15.7% and snaring at 1.0%. Digging and hole blocking were consistently higher at active main than at other types of sett, and these patterns of persecution declined generally in the order active main sett>disused main sett>annexe sett>subsidiary sett>outlying sett. It was argued that this implied that the persecution was deliberately targeted at badgers, as opposed to being incidental persecution associated with killing foxes, since the incidence of persecution declined in parallel with the levels of badger use of each sett type.

When analysing the results, the number of affected setts within a land class group or region were generally too small for statistical analysis, and so significance levels are only presented for the national changes. Also, since there was no information on persecution levels at setts missed in the 1980s survey, some of the sample sizes used in these analyses are slightly different from those in other Chapters.

7.2.1 Badger digging

Overall, the levels of badger digging at main setts had declined significantly, to just under half that recorded in the 1980s; 4% of main setts showed evidence of having been dug in the 1990s (Table 7.1). Based on the 1-3 score, there were no significant differences in the severity of digging at main setts in each land class group between the two surveys (Kruskal-Wallis; X^2=3.84, n.s.).

Table 7.1 Changes in the number of active main setts showing signs digging in the two surveys by land class group, 1988-1997

Land class group	Total number of setts found, 1980s	Number (%) of setts dug, 1980s	Total number of setts found, 1990s	Number (%) of setts dug, 1990s	significance of difference
Arable I	86	6 (7)	94	1 (1)	-
Arable II	84	10 (12)	119	7 (6)	-
Arable III	17	2 (12)	17	3 (18)	-
Pastoral IV	158	10 (6)	211	5 (2)	-
Pastoral V	52	8 (15)	84	4 (5)	-
Marginal upland VI	30	4 (13)	46	3 (7)	-
Upland VII	2	1 (2)	5	1 (0)	-
Totals	**429**	**41 (10)**	**576**	**24 (4)**	**$p < 0.01$**

Table 7.2 Regional differences in the number of active main setts showing signs of digging in the two surveys, 1988-1997.

Region	Total number of setts found, 1980s	Number (%) of setts dug, 1980s	Total number of setts found, 1990s	Number (%) of setts dug, 1990s	significance of difference
North England	16	6 (38)	19	5 (26)	-
North-west England	12	2 (17)	12	3 (25)	-
North-east England	15	3 (20)	21	0 (0)	-
West Midlands	41	5 (12)	82	1 (1)	-
East Midlands	27	5 (19)	29	2 (7)	-
Central England	18	1 (6)	26	0 (0)	-
East Anglia	8	1 (0)	14	2 (14)	-
South-west England	109	4 (4)	143	2 (1)	-
Southern England	43	3 (7)	49	3 (6)	-
South-east England	48	3 (6)	62	0 (0)	-
North Scotland	8	0 (0)	12	0 (0)	-
South Scotland	15	2 (13)	15	2 (13)	-
Mid and north Wales	27	3 (11)	46	3 (7)	-
South Wales	42	3 (7)	46	1 (2)	-
Totals	**429**	**41 (10)**	**576**	**24 (4)**	**$p < 0.01$**

Thus despite a decline in overall incidence of digging, where it still occurred the damage to main setts that had been dug remained the same. As in the 1980s, lower levels of digging were recorded for annexe and subsidiary (2% each) and outlying setts (1%) (Appendix Tables 11.9.1 to 11.9.3). Also, there had been no change in the levels of digging at these types of sett. This suggests that in the 1980s, digging was deliberately targeted at badgers, since it increased in parallel with the frequency of occupation of each type of sett. Unlike the 1980s, signs of digging were most common at disused main setts in the 1990s (6%) (Appendix Table 11.9.4). It is possible that digging activities led to some main setts being abandoned, but this is impossible to verify in a one-off study such as this.

Despite the national decline in levels of digging, locally it was still a significant problem (Table 7.2 and 10.9.5). For all types of sett, but particularly main setts, digging levels were higher in North and North-west England than for any other regions; in these two regions, a quarter of all main setts showed signs of having been dug and, contrary to the national trend, these two regions showed little change in levels of badger digging since the 1980s, and the number of badger social groups showed no significant change. Overall, although there is no significant correlation between the percent of main setts dug and the percent change in the number of badger social groups in each region (Spearman rank correlation; r_s=-0.407, n.s.), the general pattern was for no increase or a small decline in the number of main setts in areas where levels of digging are highest (Table 7.3). Whilst the overall pattern is clear, three regions (East Anglia, and Mid and north Wales and South wales) did not conform to the general trend. In the past decade, south and east Suffolk have been targeted for badger reintroduction programs, which may partly explain the pattern of increasing population despite high levels of digging. The anomalous positions of Mid and north Wales, and South

Wales are less easy to understand. It is possible that other forms of persecution which could not be quantified in the national surveys are more prevalent in these areas than elsewhere in Britain therefore confusing the observed trend with digging alone. For the rest of Britain there was a significant negative correlation between the percent main setts dug in a region and the percent change in the number of badger social groups (Spearman rank correlation; n=11 pairs, r_s=-0.754, p<0.01).

Table 7.3 Regional comparison of the levels of digging at main setts in the 1990s and the change in the number of main setts; the regions are shown in descending order of the level of digging.

Region	Percent main setts dug in the 1990s	Percent difference in number of main setts
North England	26	6
North-west England	25	-8
East Anglia	14	56
South Scotland	13	0
East Midlands	7	4
Mid and north Wales	7	35
Southern England	6	7
South Wales	2	-2
West Midlands	1	86
South-west England	1	23
North-east England	0	24
Central England	0	18
South-east England	0	15
North Scotland	0	50

7.2.2 Sett blocking

The proportion of each type of sett that had some or all holes blocked had not changed significantly for any type of sett between the two surveys (Table 7.4 and Appendix Tables 11.9.6 to 11.9.10). However, the increase in the number of setts since the 1980s has meant that the total number of blocked setts has increased. There are, however, quite large regional differences in the proportion of setts that had been blocked (Table 7.5 and Appendix Table 11.9.10). The extent of sett blocking was not related to badger population density; there was no relationship between the percent of main setts blocked and mean main sett density across regions (r_s=0.03, n.s.). Thus, it is unlikely that the majority of sett blocking was undertaken by landowners or others in response to problems caused by badgers.

Had this been a significant problem, the level of sett interference would have increased in areas where badgers were more common. In any case, such activity would be illegal unless the relevant licence had been obtained (Harris *et al.*, 1994). However, under the Protection of Badgers Act 1992, it is legal for foxhunts to block badger setts, so long as they follow specific protocols.

Despite changes in the law, the extent of hole blocking had not changed between the two surveys (Table 7.4 and Table 7.5). Furthermore, there has been little change in the degree of sett blocking; 26/66 (39%) main setts blocked in the 1980s were graded "2" or "3", whilst in the 1990s, 22/74 (30%) of blocked main setts were graded "2" or "3". Based on the 1-3 score, there were no significant differences in the severity of hole blocking at main setts between the two surveys (Kruskal-Wallis test; X^2=1.19, n.s.). Of the 74 active main setts with blocked holes in the 1990s, 15 (20%) were illegally blocked with rocks, oil drums, wire mesh and similar items. Whilst the remainder were blocked with soil, the surveyors were not asked to assess whether this had been undertaken in accordance with the provisions of the Protection of Badgers Act 1992. Thus, there is no evidence that nationally the new legislation has led to a significant improvement in the way that badger setts are blocked by foxhunts.

Table 7.4 Changes in the number of main setts showing signs of hole blocking, 1988-1997, by land class group.

Land class group	Total number of setts found, 1980s	Number (%) of setts blocked, 1980s	Total number of setts found, 1990s	Number (%) of setts blocked, 1990s	significance of difference
Arable I	86	16 (19)	94	13 (14)	-
Arable II	84	19 (23)	119	22 (18)	-
Arable III	17	2 (12)	17	2 (12)	-
Pastoral IV	158	18 (11)	211	25 (12)	-
Pastoral V	52	8 (15)	84	9 (11)	-
Marginal upland VI	30	3 (30)	46	3 (7)	-
Upland VII	2	0 (0)	5	0 (0)	-
Totals	**429**	**66 (15)**	**576**	**74 (13)**	**n.s.**

Table 7.5 Regional differences in the number of active main setts showing signs of hole blocking in the two surveys, 1988-1997.

Region	Total number of setts found, 1980s	Number (%) of setts blocked, 1980s	Total number of setts found, 1990s	Number (%) of setts blocked, 1990s	significance of difference
North England	16	4 (25)	19	3 (16)	-
North-west England	12	2 (17)	12	0 (0)	-
North-east England	15	2 (13)	21	2 (10)	-
West Midlands	41	13 (32)	82	17 (21)	-
East Midlands	27	9 (33)	29	8 (28)	-
Central England	18	5 (28)	26	5 (19)	-
East Anglia	8	2 (0)	14	2 (14)	-
South-west England	109	12 (11)	143	17 (12)	-
Southern England	43	9 (21)	49	8 (16)	-
South-east England	48	3 (6)	62	4 (6)	-
North Scotland	8	0 (0)	12	0 (0)	-
South Scotland	15	1 (7)	15	1 (7)	-
Mid and north Wales	27	3 (11)	46	5 (11)	-
South Wales	42	1 (2)	46	2 (4)	-
Totals	**429**	**66 (15)**	**576**	**74 (13)**	**n.s.**

7.2.3 Snaring at setts

Snaring in the immediate vicinity of badger setts was recorded at very low levels in both the 1980s and the 1990s (Appendix Table 11.9.11), and there was no significant change in this form of persecution.

7.3 Discussion

Badger persecution used to be widespread, and took many forms. The extent and variety of badger persecution in earlier centuries is described in Howes' (1988) review of the history of badger persecution in Yorkshire. In the early part of this century it was recorded that badgers were protected on a few estates, but these were the exception rather than the rule (Blakeborough & Pease, 1914), and on 90% of estates badgers were systematically harassed, dug-out, baited, shot or killed in other ways. If this is a reasonable assessment of the levels of badger persecution nationally, it is unsurprising that at that time many local mammal recorders considered badgers to be very rare or on the verge of extinction (Cresswell, Harris & Jefferies, 1990).

Some forms of badger persecution have now ceased. Last century, badgers were hunted at night with hounds, and Blakeborough & Pease (1914) considered that this "sport" may have led to the preservation of badgers in some areas. There is little information on badger hunting, or when it finally died out. However, during the earlier part of this century, many badgers were also killed by traditional foxhunts. For instance, for the 1926-27 hunting season, of the 107 foxhunts in England and Wales that reported their kill for the season, 14 mentioned that they had also killed a total of 50 badgers (Anon., 1927). Of these, all but five were specifically recorded as having been killed by hounds. Badgers were killed by hounds when they were found above ground; this occurred because foxhunts "stopped out" badger setts (and fox earths) at night to ensure that the foxes were above ground the next day to hunt. When setts were "hard" blocked, so that it was difficult for badgers to dig back in, they were also forced to spend the day above ground in cover. In such circumstances, they were at risk of being found and killed by the hounds. The Badgers Act 1991 made it illegal for foxhunts to block setts other than in a number of specified ways. When the methods stipulated in the Act are used, sett stopping should no longer be such a problem. However, in this current study, 20% of blocked main setts were blocked illegally with rocks, oil drums, wire mesh and similar items designed to prevent the badgers re-opening the hole. There was no evidence that the Badgers Act 1991 has reduced the problem of sett stopping nationally, although some local Badger Groups reported changes in sett-stopping by their local foxhunts. The extent of badger mortality due to foxhunting practices is unquantified.

Other forms of badger persecution continue, and the most emotive of these is badger digging, and much of the legislation to protect badgers was designed to eliminate this "sport" (Harris *et al.*, 1994). Badger digging used to be widespread, both in its own right and as an incidental activity when foxes were being dug out of badger setts. The badger population was concluded to be declining in the early 1970s, with badger digging and other forms of persecution acting as significant contributory factors (Hardy, 1975). After digging was finally banned in 1981, and by the time of the 1980s survey, levels of badger digging had declined, to such an extent that of 35 local badger protection groups expressing a view on the extent of badger digging in their area, only 16 (46%) thought that it was or could still be a problem (Cresswell, Harris & Jefferies, 1990).

The further protection afforded to badgers via the 1991 Act and the increase in the number of local badger protection groups in Britain (from 19 in 1986 to 83 in 1997) led to a reduction in the number of main setts which had been dug in the 1990s survey; this had declined to less than half that seen a decade earlier.

Cresswell, Harris & Jefferies (1990) estimated that 9000 badger setts were dug each year in the mid-1980s. They assumed that one badger was killed per dig. This assumption was supported by Griffiths (1992), who analysed the hunting diary of a badger digger. He found that over a seven year period, most successful hunting days resulted in the capture of a single badger, with a maximum of five. Cresswell, Harris & Jefferies' (1990) estimate of 9000 badgers killed by diggers each year also compared well with that produced by John Bryant (*pers. comm.*) of 10,000 badgers killed by diggers each year.

It is unlikely that such a well-established rural activity as badger digging would cease suddenly, especially when it was a widespread and serious problem in many areas prior to 1973. The little evidence that is available suggests that badger digging was undertaken by both rural and urban residents, that it has been on the decline since it was made illegal in 1981, and that this decline has continued into the 1990s. Whilst badger digging has declined generally, it remains a significant problem in North and North-west England, where a quarter of all main setts surveyed in the mid-1990s had been dug. This corresponds to a lack of increase in the number of main setts in these two regions, contrary to the trend for much of the rest of Britain. It is difficult to quantify exactly what effect on the population a 50% decline in the incidence of bader digging would have. Even more difficult to quantify is the effect of the other forms of persecution discussed, which, as mentioned, are likely to have at least as large an effect on badger mortality as digging and whether together they would be enough to account for the large increase in badger numbers. To investigate this, in Chapter eight I present the results of simple computer modelling of the badger population, and in particular its response to decreasing adult and cub mortality.

7.4 Summary

The incidence of visible signs of serious badger persecution was found to have declined by over 50% nationwide, between the two surveys. The levels of badger digging in the 1990s correlated with the patterns of change in badger numbers, on a regional basis. In the regions where badger digging was still a problem, there tended to be little increase in numbers of social groups. Signs of badger digging were considered to be visible evidence of a more widespread underlying intolerance to badgers. The progressive tightening of badger protection laws, both immediately prior to the original survey and between the two surveys, was thought to be the reason for the decline in persecution. In conclusion, I suggest that a decline in badger persecution was the primary factor driving the increase in numbers in the period between the surveys. In Chapter eight, I use simple computer models to investigate the likely underlying mechanisms by which this population change came about.

8. Understanding the changes in the British badger population

8.1 Introduction

In the previous Chapter, a large decrease in the levels of visible signs of badger persecution was found to have occurred between the two badger surveys. Of the variables available to relate to the changes in badger numbers, this appeared to be the primary causative factor. As explained in Chapter one, hitherto it had always been assumed that any changes in the badger population would be slow, and so this sudden population recovery was an unexpected result. In this Chapter, the badger population growth is analysed, and, in particular, the underlying mechanisms by which it may have occurred are considered. Population growth can occur by two underlying mechanisms: an increase in the number of young produced, and/or a decrease in mortality rates. Since a reduction in persecution levels is more likely to lead to an reduction in mortality rates rather than an increase in fecundity, the impact of changes in adult survival on both population size and rates of population growth was of particular interest. Based on the modelling results, possible future changes in the badger population in Britain are also considered.

8.2 Methods

8.2.1 *Modelling the growth of the badger population*

Simple computer models were used to examine the relative importance of changes in fecundity and adult survivorship in driving badger population growth. The aim was simply to try to understand how the observed rates of population increase could have occurred, and whether this conforms to the hypothesis that the badger population benefited from a decrease in persecution levels.

8.2.2 Background to the model

The model used for these analyses was RAMAS (Applied Biomathematics, Setauket, New York, 11733). This is a Leslie-matrix model which incorporates data on age structure, fecundity and adult survivorship; both fecundity and survivorship can change with age (Ferson & Akçakaya, 1988). This type of model can, therefore, be used to analyse changes in both population size and age structure. A further advantage of a Leslie-matrix model is that it can be used to estimate the rate of increase of a population (Usher, 1972). For this, eigenvalues (lambda) are calculated; when lambda=1, the population is stable, when lambda >1, the population is increasing, and when lambda<1 the population is decreasing.

Density dependence can also be included in the model, in the form of the logistic equation:-

$$R=N\,[1+r\,((K-N)\,/\,K)]$$

where the annual recruitment to the first age class, R, is a density dependent function of N, the number of cubs produced each year. In RAMAS, K represents the level of recruitment that occurs at the equilibrium population density, and r is a parameter which determines the level of change in recruitment as density changes. At low densities, approximately 1+r x the potential number of offspring become recruits, and this amounts to an increase in fecundity at low densities (Ferson & Akçakaya, 1988). Random variation is introduced to the model by adding a coefficient of variation of 0.1 into the estimates of fecundity and adult survivorship.

8.2.3 Parameters used in the analyses

In developing these models, I used data on badger population biology published by Anderson & Trewhella (1985), Cheeseman *et al.* (1987; 1988), Harris & Cresswell (1987), Cresswell *et al.* (1992), Harris, Cresswell & Cheeseman (1992), Page, Ross & Langton (1994) and White & Harris (1995). The information used in the RAMAS analyses are summarised in Table 8.1. The initial adult population size fluctuated around 60 adults, which produced 40 cubs. Values of r=0.5 and K=40 produced a stable model population (lambda=1). During the simulations, the age structure will vary slightly because of the stochastic variation included within the model. The figures for fecundity were based on the figures given by Cresswell *et al.* (1992), and females did not breed until their fourth year. The 60 adult badgers were assumed to be spread across 10 social groups, each containing six adult badgers. The adult population was also biased towards females, such that 70% of adults were female. This reflects the situation seen in the most intensively studied badger population, at Woodchester Park, where the sex ratio of cubs is roughly equal but the adult population is heavily skewed towards females. This reflects the higher mortality rate for adult males than females (Cheeseman *et al.*, 1987; Harris & Cresswell, 1987). To make the predictions of the model as realistic as possible, density-dependent effects on productivity were included. In real badger populations the overall fecundity of females is reduced at high densities (Cresswell *et al.*, 1992). Woodroffe & Macdonald (1995) found that in larger groups a greater proportion of females lost their cubs, and Rogers, Cheeseman & Langton (1997) produced evidence for detrimental density-dependent effects on adult body weight. In this model, the number of cubs produced did not rise in parallel with the number of adults: density dependence limited the number of cubs that were produced. Conversely, if the population declined, the fecundity per female rose.

Table 8.1 The initial data used in the *RAMAS* model; the sources for the data are explained in the text.

Age Class	Number in age class	Fecundity	Suvivorship
Cub	40	0	0.60
Second year	20	0	0.70
Third year	14	0	0.70
Fourth year	10	2	0.70
Fifth year	7	2	0.70
Sixth year	5	2	0.70
Seventh year	3	2	0.70
Eighth year and older	1	2	0.70

8.3 Results

8.3.1 Output from the model

From a stable population, fecundity and adult survivorship were increased by increments of 10% to examine their relative effects on population size. For each run of the model, 50 simulations were undertaken. The stochasticity applied to the fecundity and adult survivorship values caused each run to be slightly different. Each simulation lasted twenty years.

The results are compared in Figure 8.1 and Figure 8.2. After changing either fecundity or adult survivorship, the badger population responded rapidly, and appeared to be reaching a new equilibrium size within ten years. However, of the two parameters, a consistent increase in adult survivorship had the biggest impact; a 10% increase in adult survivorship led to a 55% increase in badger numbers in ten years. To obtain a 75% increase in the badger population, adult survivorship had to be increased by 18%. Then the badger population rose rapidly, increasing by 75% in six years. After this, the population declined because of a reduction in fecundity brought about by the density-dependent aspect built into the model.

In reality, the badger population would be unlikely to reach a stable end point. In Britain there are still large numbers of apparently suitable 1-km squares that are not yet occupied by badgers. It is likely, therefore, that dispersal, which was not included in the model population, would lead to the establishment of new social groups, thereby mitigating the effects of a density-dependent reduction in fertility. Thus, the decline seen in the model population would be unlikely to occur in reality, and the increase would continue. Our field data also suggest that dispersal would occur after the badger population had reached a critical density; in section 4.3 it was shown that new social groups were established after a population increase of roughly 25% on the 1980s population. Changes in fecundity did not bring about such striking changes in population size. In fact, increased levels of fecundity could not bring about a 75% increase in population size. This is because density-dependent effects reduced the likelihood of offspring surviving, and there is an upper limit on the number of cubs produced per social group. This is consistent with the observations of Cresswell *et al.* (1992), who found that there was no net reproductive gain from living in a large social group, and that there was a decline in productivity per adult with increasing group size. Thus, in the model, increasing fecundity from two to three offspring per female only led to a population increase of 30%, and further increases in fecundity did not lead to further increases in population size.

8.3.2 Comparison with real data

There are few data available to show whether either fecundity or adult survivorship have changed in British badger populations. At Woodchester Park, social group size has been monitored since 1978. The data from there provide a useful dataset to study in view of the results presented here. At Woodchester, the initial mean group size was less than three adults. In the early years the number of animals may have been under-estimated (Cheeseman *et al.*, 1987). Using the data for the years 1985 to 1994, which provide the most accurate measure of population size, mean group size at Woodchester increased from 5.3 to 8.8, an increase of 66% (Figure 8.3). Using the model, it was calculated that this rate of growth would have been achieved by increasing adult survivorship by 14%. So there is some evidence to suggest that changes in the level of adult survivorship that used in the models are realistic, and could be achieved in real badger populations.

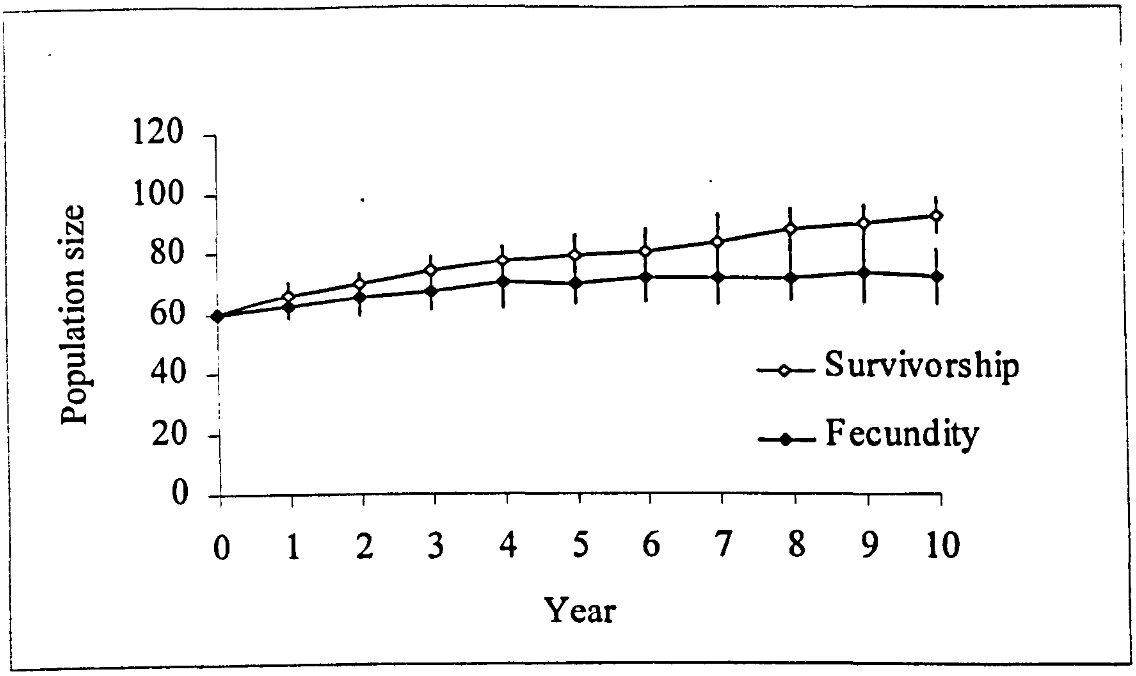


Figure 8.1 The effect of increasing fecundity and survivorship by 10% per annum on the size of the model badger population. The figures are the means ± s.d. for 50 runs of the model

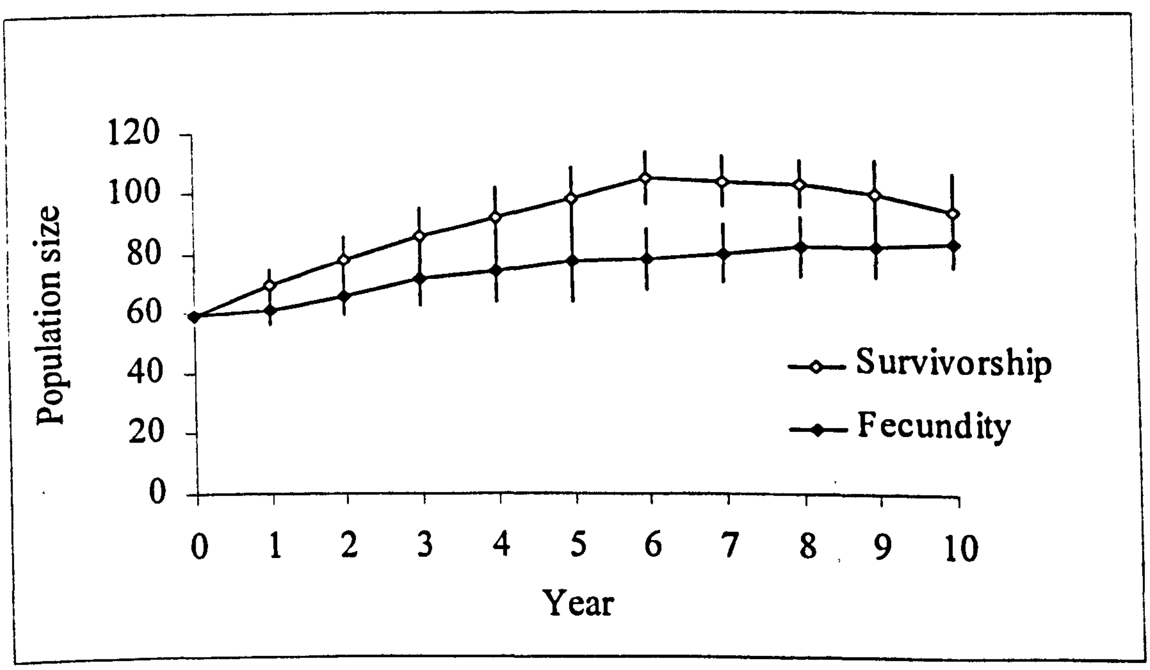


Figure 8.2 The effect of increasing fecundity and survivorship by 18% per annum on the size of the model badger population. The figures are the means ± s.d. for 50 runs of the model

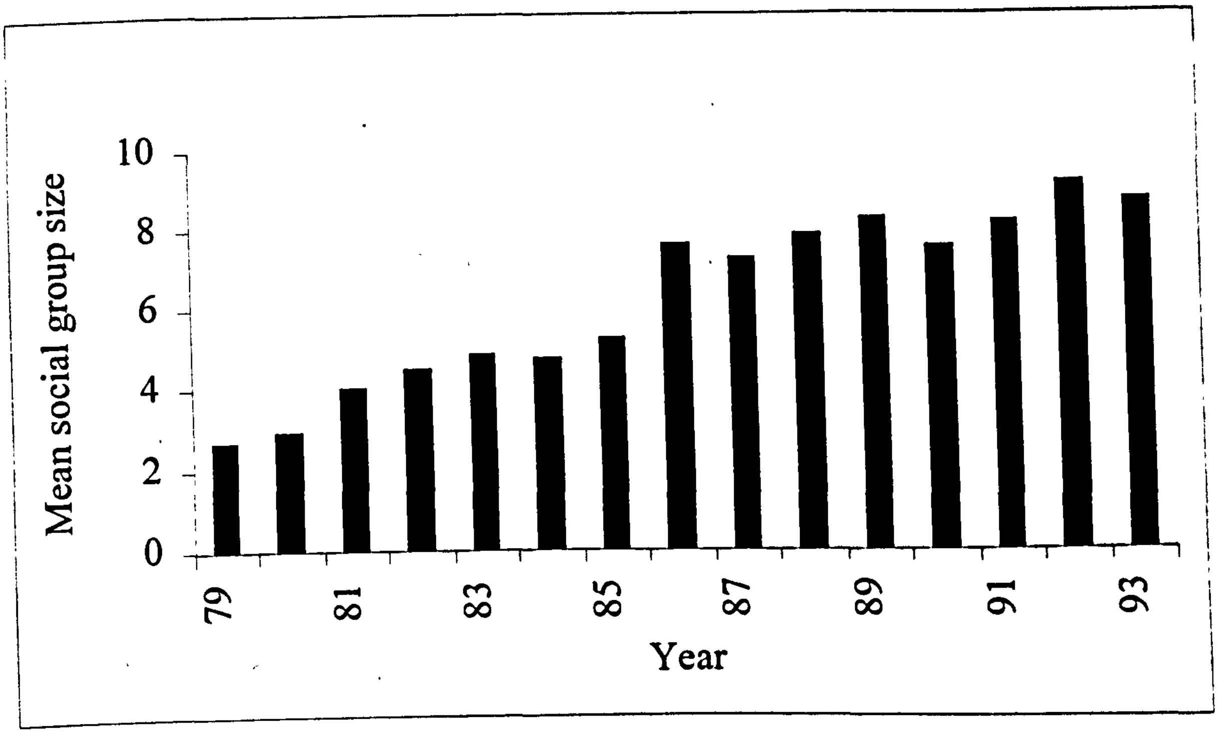


Figure 8.3 Changes in the mean number of adult badgers per social group for the same 21 social groups at Woodchester Park, Gloucester. Data supplied by Dr. Chris Cheeseman

8.4 Discussion

8.4.1 Conclusions from the modelling study

Although theoretical, the population simulations presented here are useful in helping elucidate the effects of changes in fecundity and adult survivorship. The main aim was to determine whether increased fecundity, or adult survivorship, was most likely to lead to the observed increase in the badger population. The conclusion is clear: consistent, moderate changes in adult survivorship can lead to substantial increases in the population, to a similar level to that which has been observed in the nine years between the surveys. Badger populations can respond quickly to changes in adult survivorship. Changes in fecundity alone could not have led to the estimated population changes. The data from Woodchester Park indicates that the rates of population change calculated are entirely plausible.

In the simulations, the main effect of density dependence was to make the model populations grow more slowly as they approached carrying capacity. The initial social group size used in the simulations was relatively large, therefore the populations in the model grew more slowly than would be the case if there were no density dependent effects. However, density dependent effects would not limit the growth of new social groups. Females in newly established, smaller groups would have a higher fecundity than those in well-established, and hence larger, social groups. So when the effect of increasing number of social groups is included, the potential rate of population increase will be higher than the growth rates predicted by the model.

Assuming an average badger social group size of 4.8 adults, as estimated for the 1980s in Chapter five, an increase in survivorship of 18% per annum means in reality the survival of less than one extra animal per year. A trend such as this would bring about the magnitude of the population increase that was estimated to have occurred in Britain, in less than 10 years. When considering that there are many newly established social groups, which are likely to be smaller and therefore faster growing on average, perhaps a still smaller increase in survivorship would bring about the observed increase in numbers. This increase in adult survival could occur in a number of ways: a reduction in levels of sett destruction, digging, snaring and/or lamping could all have contributed, and the relative importance of these various factors is likely to differ regionally.

There are other factors that could have contributed to a change in badger numbers. The two factors most frequently cited are changes in weather conditions and changes in cropping patterns, particularly an increase in novel crops such as maize. These would not have been recorded in the badger survey. There are no quantified data on the impact of weather or agricultural changes on badger fecundity or survival. However, the main impact of adverse weather patterns is on cub, rather than adult, survival (Neal & Cheeseman, 1996). The analyses presented here implied that changes in adult survival have the greatest effect on population size, as would be expected in a long-lived species such as the badger. Adverse weather conditions would therefore have a small effect on badger population size, unless they continued over a series of years. As for new cropping patterns, there are some data available on the impact of changes from pasture to cereals on badger populations (Kruuk & Parish, 1985), but not for other types of crop. However, the changes in badger numbers have been widespread, and there have been substantial increases in areas where little or no maize is grown. Thus this particular land use change is unlikely to have played a major role in the overall badger population increase.

The modelling work supports the assessment that the increase in badger populations over the last few years could have resulted from reduced levels of persecution leading to an increase in adult survival. Evidence that widespread but low levels of persecution have an impact on badger populations comes from the long-term study at Woodchester Park. Following the onset of the Ministry of Agriculture Fisheries and Food's study on this site, the badgers were intensively monitored and, hence, protected: the badger population at this site has grown steadily since the study began (Neal & Cheeseman, 1996).

8.4.2 The colonisation of new areas

In most studies to date, dispersal movements by badgers were found to be rare, with conflicting evidence as to whether it occurs less often at higher badger densities (Cheeseman *et al*, 1988; da Silva, Macdonald & Evans, 1994). At Woodchester Park, however, animals were more likely to move from large to small groups than vice versa (Chris Cheeseman, *pers. comm.*).

Most data on badger dispersal patterns come from studies of dispersal within established, high density badger populations rather than dispersal into vacant habitats, which is an important gap in our understanding. More information is required on how badgers disperse into new areas, and how, contrary to accepted theory, so many new social groups were established in a relatively short period of time. The results of this study suggest that the increase in badger numbers came about firstly through increasing social group sizes, followed by increasing number of social groups and expansion into new areas. Dispersal of coalitions of individuals from the same social group, as has been observed at Woodchester (Chris Cheeseman, *pers comm.*) and Wytham (Woodroffe *et al.*, 1993) is a possible mechanism facilitating the rapid establishment of new social groups.

8.4.3 Timing of the badger population changes.

With two independent snapshot sampling events, it is impossible to determine how the population changes occurred over that time period. Equally, it is impossible to determine current trends; the badger population could, for instance, have reached a peak a before the onset of the second survey, and already be in decline again.

The most recent piece of legislation enhancing the protection of badgers (Badgers Act 1991) did not become law until 25 October 1991, just four years before the onset of this survey. The model suggests that even with an increased adult survival of 18%, it would take at least six years for the badger population to grow by 75%. It is highly unlikely that all the increase has occurred since that legislation was passed. I suggest that the population was already on the increase at the time of the original 1980s survey due to the Wildlife and Countryside Act 1981 taking effect, and that this has continued for much of the period prior to this second survey. A survey of Midland farmers in the early 1980s showed that half the farmers with badgers on their land welcomed them, and only 2% regarded them as a considerable nuisance (Macdonald, 1984). However, the local Badger Protection Groups also generally agreed that sett destruction had been, or remained, a problem, and that there was a minority of farmers that continued to resent the presence of badgers on their land. This reinforced the results of this study; illegal sett destruction remains a problem, even if it only by a minority of landowners.

In the time following the Protection of Badgers Act 1992 however, the attitudes of a cross-section farmers and landowners appeared to change to a degree, following the release of a report by the National Farmers' Union (Anon, 1995). This report argued that there were "unnaturally high" populations of badgers on some areas, and that these posed a significant disease risk to cattle. This report was followed by a widespread campaign reinforcing this view. A number of Badger Protection Groups reported that in response to this campaign farmers were far less tolerant of the badgers on their land, and that there had been a rise in levels of interference with badger setts. It was felt that badger numbers in their area were no longer increasing and may even already be declining. The modelling work here has highlighted the sensitivity of the badger population to changes in adult mortality rates. Thus it is equally likely that the population will undergo equally rapid decline should persecution levels, and hence adult mortality rates increase.

8.4.4 *Future badger population changes*

In this Chapter, it has been shown that badger populations can respond quickly to changes in adult survivorship, and that the estimated changes in the badger population in Britain could have occurred in the nine years between the two surveys as the result of moderate but consistent and widespread reductions in the rate of adult mortality. I conclude that progressive tightening of the laws conferring protection to badgers has brought about a reduction persecution which has led to this increase in adult survival.

There are substantial areas of lowland Britain where badgers are still absent, even though the habitat is apparently suitable for them. It would be expected that, assuming persecution levels do not rise again, these areas will continue to be recolonised, and that badgers will continue to expand their range within Britain. In this scenario, the colonisation of new areas is likely to be slow. Despite the considerable growth of the population in the decade or so separating the two surveys, only an additional 4% of Britain's 1-km squares were colonised by badgers. The contractionist nature of badger behavioural ecology outlined in Chapter one means that in any given area, they are only likely to exhibit a range expansion when a certain threshold of average group size is surpassed (section 4.3.7).

8.5 Summary

In conclusion, the model output suggested that the badger population is relatively sensitive to changes in adult badger mortality. As outlined previously, there are a number of other forms of persecution which leave no quantifable field signs. There is no doubt that the law passed as the Wildlife and Countryside Act 1981 deterred farmers and landowners from openly killing badgers. It is extremely likely that there has been a decline in these pursuits in parallel with the decline in digging. Therefore, I suggest that a widespread decline in persecution, leading to a moderate but consistent increase in adult survivorship was the major contributory factor driving the increase in the badger population in Britain between 1988 and 1997.

9. Discussion and conclusions

9.1 *The changing badger population, 1988-1997*

In the decade between the original stratified badger survey, and the first repeat carried out as part of this project, the "snapshot" picture produced showed that the population in Britain had increased significantly. As with the examples of the mule deer and the passenger pigeon described in Chapter one, the badger population is sensitive to extrinsic factors impinging upon it. The results presented in this thesis imply that the badger population has historically been suppressed to a level considerably lower than its potential, but that this situation has been redressed to some extent over the period between the surveys.

The patterns of change in badger social groups throughout Britain were found not to be uniform. Much of the 24% increase in social groups took place in the pastoral landscapes, irrespective of the badger density in these areas at the time of the original survey. There were also increases in the number of social groups in Arable II, which covers much of the eastern English agricultural area, and Marginal upland VI which extends over much of upland Wales. On a simple, geographical basis the situation was also complex. Some regions showed a large increase in social group number, while others did not, or even underwent a decline.

The change in numbers of social groups was only part of the story. It has been shown in this project, and elsewhere (Rogers *et al*, 1997), that the badger population can increase via two routes: increases in social group size, and increases in number of social groups. Even without a noticeable pattern of colonisation of new areas, the size of the population can increase considerably through group size increases. The possibility of a threshold group size after which new groups start to appear was revealed in this thesis. For any given area, this threshold will vary according to the existing density of badgers and the carrying capacity of the habitat.

In this study, there were significant increases in mean group size across the country in addition to the increase in social group number, reflected in disproportionate changes in numbers of smaller sett types, larger main setts, and higher levels of activity throughout the 1-km squares. These changes were not always in parallel with the patterns of social group change. For example, in some regions there was a large expansion in the number of social groups, there was little change in the size of the social groups. Conversely, in other regions where there was little change in the number of main setts, mean social group size increased significantly. Patterns of change in the badger population are clearly very complex. The reasons for this are likely to be manifold. Britain's landscape is extremely variable, even at relatively local scales. The same applies to traditional land use and historical patterns of the treatment of badgers. The observed patterns of changes in group size and number, whatever the cause, will be influenced by a number of parameters: carrying capacity of the habitat; availability of suitable sett sites; historical and current patterns of persecution etc.

9.2 Why did the population increase so dramatically?

The fact that the population increased so considerably from the time of the original survey, to the time of this update survey implies that a fundamental extrinsic factor with a controlling effect on the population had changed to allow growth in numbers. It seemed unlikely before this survey that badger numbers and distribution were limited by resources. It is true that locally, the density of badgers will eventually be limited by food resources (Kruuk & Parish, 1982). However, the original badger survey (Cresswell, Harris & Jefferies, 1990) revealed that a minority of Britain's 1-km squares contained badgers, with many apparently suitable squares remaining empty. Analysis of the habitat data collected in the surveys highlighted those habitats which were important in determining the likelihood of badger presence, and those habitat types which were in greater abundance in areas with badgers present. These were primarily habitats associated with cover and potential foraging ground. There were no trends between the two surveys in the availability of these habitat types that would be expected to drive the population upward. In fact, the opposite is true; availability of positively selected habitat types declined slightly overall, as did the proportion of 1-km squares which were classed as "good" badger squares on the basis of heterogeneity.

The other potentially important factor was changes in "predation" levels - the impact of human activities on the population. Tightening of badger protection laws, immediately prior to the original survey, and between then and the second survey, had the potential to have a positive effect on badger numbers. There was indeed a significant decline in evidence of persecution between the two surveys. As the human pressure has been reduced via this increased protection, badgers numbers have responded accordingly by increasing throughout much of the country. This result came as some surprise. Much of the legislation protecting badgers had been passed on animal welfare rather than conservation grounds, and the depressive effect of human activities on badger numbers was not fully appreciated. The population was considered to be stable (Neal, 1990; Griffiths, 1993), and any recovery was expected to be slow. The high density populations from which the research basis of this assessment was drawn are unlikely to be typical of the population as whole (Kruuk & Macdonald, 1985; Cheeseman *et al.*, 1993), and information on the population fluctuation processes in other areas is sparse.

It can be concluded that the laws surrounding badgers have succeeded, given that there has been a positive effect on numbers stemming directly from protection afforded to them. There are associated problems with this trend of increasing badger numbers, but these are beyond the scope of this thesis.

9.3 Future trends and research

Given the extent of the expansion of the badger population in Britain in such a relatively short time, their future success seems assured. There are, however, some results which should be highlighted. Persecution in parts of the country was still a problem at the time of the second survey, with the effect of continuing to depress the population in those areas. If this pattern were to be repeated elsewhere in the country, then the upward trend in numbers would be reversed. Indeed, since the completion of the survey, there is evidence to suggest that this may already have occurred in places (E. King, *pers. comm.*). In view of the the increasing problems with tuberculosis incidence in cattle in which badgers are implicated (Krebs 1997), and since the publication of the National Farmers Union report (Anon. 1995), tolerance towards badgers is undoubtedly on the decline in some areas. It cannot be assumed that the trend for increasing badger numbers that occurred between 1988 and 1997 will continue, as this would only be the case given unchanged presecution levels. Therefore, it is important that the badger population continues to be monitored, at both local and national levels. Overall trends can only be monitored using large-scale, structured monitoring schemes such as the one described in this thesis. Locally, badger protection groups and wildlife organisations can continue to protect and monitor badgers in their own areas.

At a local scale, the need to be able to estimate badger densities is more important then ever before. Much research funding is now being made available for research into the role badgers play in the ongoing bovine tuberculosis problem in south west Britain. A key factor in the success of areas of this research will be the obtaining of reliable data on badger density: estimates based on social group density lack accuracy due to the variability of group size. Social group size is suspected to be a factor in the epidemiology of the disease (White & Harris, 1995). The technique of badger group size estimation outlined in this thesis may eventually prove useful in this context. The method, although promising, remains untested on comparable datasets and further work is required to refine it.

There remains large gaps in our knowledge of badger populations. This thesis has shown that the badger population in Britain is clumped. However, the monitoring scheme described here is designed to detect trends at a large scale. Few data exist on how the changes in numbers and distribution actually occur. For every pocket of high badger density, there are many others, often apparently suitable for badgers, where density is very much lower. Why this is so is unclear, particularly given the low habitat specificity of the species. Until recently, there were no data available at a level between the large-scale survey reported here, and the very intensive, local-scale research carried out at a small number of sites. Recently, in new research at Bristol University and Liverpool University, badger and habitat distribution have been mapped over three separate 10 x 10 km squares in areas of varying badger density. It is hoped that, when complete, the results of these studies will complement the national survey and increase our understanding of the reasons for the observed patterns of badger distribution in our landscape today.

10. References

Anderson, R.M. & Trewhella, W. (1985) Population dynamics of the badger (*Meles meles*) and the epidemiology of bovine tuberculosis (*Mycobacterium bovis*). *Philosophical Transactions of the Royal Society of London, series B*, **310**, 327-381.

Anon. (1927) *The hunting diary for 1927-28 - a guide and handbook for followers of hounds.* London: Walter Goldsmith & Co.

Anon. (1995) *Badgers: their effect on agriculture and the countryside.* Unpublished report by the National Farmers' Union, London

Anon. (1996) *Review of the potential effects of climate change in the United Kingdom.* London: HMSO.

Barr, C.J., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. & Ness, M.J. (1993) *Countryside survey 1990: main report.* London: Department of the Environment.

Barr, C., Gillespie, M. & Howard, D. (1994) *Hedgerow survey 1993 (stock and change estimates of hedgerow length in England and Wales, 1990-1993).* Cumbria: Institute of Terrestrial Ecology.

Blakeborough, J.F. & Pease, A.E. (1914) *The life and habits of the badger.* London: The Foxhound.

Bright, P.W. (1993) Habitat fragmentation - problems and predictions for British mammals. *Mammal Review*, **23**, 101-111

Brown, J.A. (1993) Transmission of bovine tuberculosis (*Mycobacterium bovis*) from badgers

(*Meles meles*) to cattle. Unpublished PhD thesis, University of Bristol.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C. & Lane, A.M.J. (1996) Land classification for strategic ecological survey. *Journal of Environmental Management*, **47**, 37-60.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C. & Lane, A.M.J. (1997) ITE Merlewood land classification of Great Britain. *Journal of Biogeography*, **44**, 340-319.

Butler, J.M. & Roper, T.J. (1996) Ectoparasites and sett use in European badgers. *Animal Behaviour*, **52**, 621-629.

Cheeseman, C.L., Cresswell, W.J., Harris, S. & Mallinson, P.J. (1988) Comparison of dispersal and other movements in two badger (*Meles meles*) populations. *Mammal Review*, **18**, 51-59.

Cheeseman, C.L., Jones, G.W., Gallagher, J. & Mallinson, P.J. (1981) The population structure, density and prevalence of tuberculosis (*Mycobacterium bovis)* in badgers (*Meles meles*) from four areas in south-west England. *Journal of Applied Ecology* **18**, 795-804.

Cheeseman, C.L., Mallinson, P.J., Ryan, J. & Wilesmith, J.W. (1993) Recolonisation by badgers in Gloucestershire. In: *The badger* (ed. T.J. Hayden), pp. 78-93. Dublin: Royal Irish Academy.

Cheeseman, C.L., Wilesmith, J.W., Ryan, J. & Mallinson, P.J. (1987) Badger population dynamics in a high-density area. *Symposia of the Zoological Society of London*, **58**, 279-294.

Clements, E.D. (1974) National Survey in Sussex. *Sussex Trust for Nat. Cons. Mamm. Rep. for 1970/1*

Clements, E.D., Neal, E.G. & Yalden, D.W. (1988) The national badger sett survey. *Mammal Review*, **18**, 1-9

Cochran, W.G. (1963) *Sampling techniques*. New York: John Wiley & Sons.

Cowlin, R.A.D. (1972) The distribution of the badger in Essex. *Essex Naturalist*, **33**, 1-8.

Cresswell, P., Harris, S. & Jefferies, D.J. (1990) *The history, distribution, status and habitat requirements of the badger in Britain*. Peterborough: Nature Conservancy Council.

Cresswell, W.J., Harris, S., Cheeseman, C.L. & Mallinson, P.J. (1992) To breed or not to breed: an analysis of the social and density-dependent constraints on the fecundity of female badgers (Meles meles). *Philosophical Transactions of the Royal Society of London Series B*, **338**, 393-407.

da Silva, J., Macdonald, D.W., & Evans, P.G.H. (1994) Net costs of group living in a solitary forager, the Eurasian badger (*Meles meles*). *Behavioural Ecology*, **5**, 151-158.

Doncaster, C.P. & Woodroffe, R. (1993) Den site can determine shape and size of badger territories: implications for group-living. *Oikos*, **66**, 88-93.

Dunwell, M.R. and Killingly, A. (1969) The distribution of badger setts in relation to the geology of the Chilterns. *Journal of Zoology, London.* **158**: 204-208

Elton, C. (1930) *Animal Ecology and Evolution*. Oxford University Press.

Feore, S.M. (1994) *The distribution and abundance of the badger (Meles meles L) in Northern Ireland*. Unpublished PhD thesis, Queen's University of Belfast.

Feore, S., Smal, C.M. & Montgomery, W.I. (1993) Survey of badger setts in Northern Ireland: progress report. In: *The badger* (ed. T.J. Hayden), pp. 23-25. Dublin: Royal Irish Academy.

Ferson, S. & Akçakaya, R.H. (1988) *Modelling fluctuations in age-structured populations*. New York: Applied Biomathematics.

Fletcher, M.R., Hunter, K. & Barnett, E.A. (1995) *Pesticide poisoning of animals 1994: investigations of suspected incidents in the United Kingdom*. London: Ministry of Agriculture, Fisheries and Food.

Greenwood, J.J.D. (1996) Basic techniques. In: *Ecological census techniques - a handbook* (ed. W.J. Sutherland), pp. 11-110. Cambridge: University Press.

Griffiths, H.I. (1992) Police prosectutions and badger persecution in England and Wales. *Animal Welfare*, **1**, 291-296.

Griffiths, H.I. & Thomas, D.H. (1993) The status of the badger *Meles meles* (L., 1758) (Carnivora, Mustelidae) in Europe. *Mammal Review*, **23**, 17-58.

Hair, J.F., Anderson, R.E., Tatham, R.L. & Black, R.L. (1995) *Multivariate Data Analysis with Readings*. New Jersey: Prentice.

Hancox, M.K., (1973) Studies on the ecology of the Eurasian badger (*Meles meles*). Unpublished report, Elton Library, Oxford.

Hancox, M. (1980) Parasites and infectious diseases of the Eurasian badger *(Meles meles*): a review. *Mammal Review*, **10**, 151-162.

Hansson, L. (1979) Field signs as indicators of vole abundance. *Journal of Applied Ecology* **16**, 339-347.

Hardy, P. (1975) *A lifetime of badgers*. Newton Abbot: David & Charles.

Harris, S. (1984) Ecology of urban badgers *Meles meles*: distribution in Britain and habitat selection, persecution, food and damage in the city of Bristol. *Biological Conservation*, **28**, 349-375.

Harris, S. (1984) The status of the badger (Meles meles) in Britain, with particular reference to East Anglia. *Transactions of the Suffolk Naturalists' Society*, **29**, 104-112.
Harris, S. & Cresswell, W.J. (1987) Dynamics of a suburban badger (*Meles meles*) population. *Symposia of the Zoological Society of London*, **58**, 295-311.

Harris, S., Cresswell, W.J. & Cheeseman, C.L. (1992) Age determination of badgers (*Meles meles*) from tooth wear: the need for a pragmatic approach. *Journal of Zoology, London*, **228**, 679-684.

Harris, S., Cresswell, W., Reason, P. & Cresswell, P. (1992) An integrated approach to monitoring badger (*Meles meles*) population changes in Britain. In: *Wildlife 2001: populations* (eds D.R. McCullough & R.H. Barrett), pp. 945-953. London: Elsevier Applied Science.

Harris, S., Jefferies, D., Cheeseman, C. & Booty, C. (1994) *Problems with badgers?*, 3rd edition. Horsham: Royal Society for the Prevention of Cruelty to Animals.

Harris, S., Morris, P., Wray., S. & Yalden, D. (1995) *A review of British mammals: population estimates and conservation status of British mammals other than cetaceans.* Peterborough: Joint Nature Conservation Committee.

Hill, M.O., Bunce, R.G.H. & Shaw, M.W. (1975) Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. *Journal of Ecology*, **63**, 597-613.

Howes, C.A. (1988) A review of badger persecution in Yorkshire. *Imprint, The Yorkshire Mammal Group Newsletter*, **10**, 5-12.

Hutchings, M.R. (1996) The risk of transmission of bovine tuberculosis (Mycobacterium bovis) posed to cattle by badgers (*Meles meles*). Unpublished PhD thesis, University of Bristol.

Krebs, C.J. (1989) *Ecological methodology*. New York: Harper & Row.
Krebs, C.J. (1985) *Ecology: The experimental analysis of distribution and abundance*. 3rd ed. New York, Harper and Row.

Krebs, J. (1997) *Bovine tuberculosis in cattle and badgers*. Report to the Rt Hon Dr. Jack Cunningham MP. Ministry of Agriculture, Fisheries and Food.

Kruuk, H. (1978a) Foraging and spatial organisation of the European badger, (*Meles meles* L.) *Behaviour Ecology and Sociobiology* 4, 75-89.

Kruuk, H. (1978b) Spatial organization and territorial behaviour of the European badger *Meles meles*. *Journal of Zoology, London*, **184**, 1-19.

Kruuk, H. & Macdonald, D. (1985) Group territories of carnivores: empires and enclaves. In: *Behavioural ecology - ecological consequences of adaptive behaviour* (eds. R.M. Sibley & R.H. Smith), pp. 521-536. Oxford: Blackwell Scientific Publications.

Kruuk, H.& Parish, S. (1982) Factors affecting population density, group size and territory size of the European badger (Meles). *Journal of Zoology, London*, **196**, 31-39

Kruuk, H., Parish, T., Brown, C.A.J., & Carrera, J. (1979) The use of pasture by the European badger (*Meles meles*). *Journal of Applied Ecology*, **16**, 453-459

Lack, D. (1954) *The natural regulation of animal numbers*. Oxford University Press.

Langley, P.J.W. & Yalden, D.W. (1977) The decline of the rarer carnivores in Great Britain during the nineteenth century. *Mammal Review*, **7**, 95-116.

McDonald, R.A., & Harris, S. (In prep.) Gamekeeper trapping records in relation to the status of stoats and weasels.

Macdonald, D.W. (1984) A questionnaire survey of farmers' opinions and actions towards wildlife on farmlands. In: *Agriculture and the environment* (ed. D. Jenkins), pp. 171-177. Cambridge: Institute of Terrestrial Ecology.

Macdonald, D.W., Mace, G. & Rushton, S. (1998) *Proposals for future monitoring of British mammals*. London: Department of the Environment, Transport and the Regions.

Magurran, A.E. (1988) *Ecological diversity and its measurement*. London: Croom Helm.

McClung, R.M. (1993) *Lost Wild America*. Conneticut: Linnet Books.

Millais, J.G. (1905) *The mammals of Great Britain and Ireland*, vol. II. London: Longmans, Green & Co.

Mooty, J.J. & Karns, P.D. (1984) The relationship betweeen white-tailed deer track counts and pellet-group surveys. *Journal of Wildlife Management*, **48**, 275-278.

Montgomery, W.I. (1987) The application of catch-mark-recapture techniques to the enumeration of mammal populations. In: Harris, S.(Ed) Mammal Population Studies. *Symposia of the Zoological Society of London*, **58**, 25-58.

Neal, E. (1972) The national badger survey. *Mammal Review*, **2**, 55-64

Neal, E. (1990) *The Natural History of Badgers*. London: Helm.

Neal, E. & Cheeseman, C. (1996) *Badgers*. London: Poyser

Neal, E. & Roper, T.J. (1991) The environmental impact of badgers (*Meles meles*) and their setts. In P.S. Meadows and A. Tufail (eds), *The environmental impact of burrowing animals and animal burrows*, 89-106. London. Zoological Society of London.

O'Corry-Crowe, G., Eves, J. & Hayden, T.J. (1993) Sett distribution, territory size and population density of badgers (*Meles meles* L.) in East Offaly. In: *The badger* (ed. T.J. Hayden), pp. 35-56. Dublin: Royal Irish Academy.

Page, R.J.C., Ross, J. & Langton, S.D. (1994) Seasonality of reproduction in the European badger *Meles meles* in south-west England. *Journal of Zoology, London*, **233**, 69-91.

Pease, A.E. (1898) *The badger*. London: Lawrence & Bullen.

Poulsen, J.G., Sotherton, N.W. & Aebischer, N.J. (1998) Comparative nesting and feeding ecology of skylarks (*Alauda arvensis*) on arable farmland in southern England with special reference to set-aside. *Journal of Applied Ecology*, **35**, No. 1, 131-148.

Potts, G.R. (1980) The effects of modern agriculture, nest predation and game management on the population ecology of partridges (*Perdix perdix* and *Alectoris rufa). Advances in Ecological Research*, **11**, 1-79.

Putman, R.J. (1984) Facts from faeces. *Mammal Review*, **14**, 79-97.

Reason, P., Harris, S. & Cresswell, P. (1993) Estimating the impact of past persecution and habitat changes on the numbers of badgers (*Meles meles)* in Britain. *Mammal Review*, **23**, 1-15.

Rodwell, J. (1990) *British plant communities*. 5 vols. Cambridge: Cambridge University Press.

Rogers, L.M., Cheeseman, C.L., Mallinson P.J. & Clifton-Hadley R. (1997). The demography of a high density badger (*Meles meles*) population in the west of England. *Journal of Zoology, London*, **242**: 705-728

Roper, T.J. (1993) Badger setts as a limiting resource. In: *The badger* (ed. T.J. Hayden), pp.

26-34. Dublin: Royal Irish Academy

Roper, T.J. (1992a) Badger (*Meles meles*) setts: their architechture, internal environment and function. *Mammal Review*, **22**, 43-53

Roper, T.J. (1992b) The structure and function of badger setts. *Journal of Zoology, London* **227**, 691-698.

Roper, T.J. & Christian, S.F. (1992) Sett use in badgers (*Meles meles*). In: *Wildlife telemetry: remote monitoring and tracking of animals* (eds I.G. Priede & S.M. Swift), pp. 661-669. London: Ellis Harwood.

Roper, T.J, Conradt, L., Butler, J., Christian, S.E., Ostler, J., & Schmid, T.K. (1993) Territorial marking with faeces in badgers (*Meles meles*): a comparison of hinterland and boundary latrine use. *Behaviour*, **127**, 289-307.

Roper, T.J. & Kemenes, I. (1997) Effect of blocking of entrances on the internal environment of badger (Meles meles) setts. *Journal of Applied Ecology*, **34**, 1311-1319

Skinner, C., Skinner, P. & Harris, S. (1991a) The past history and recent decline of badgers *Meles meles* in Essex: an analysis of some of the contributory factors. *Mammal Review*, **21**, 67-80.

Skinner, C., Skinner, P. & Harris, S. (1991b) An analysis of some of the factors affecting the current distribution of badger (*Meles meles)* setts in Essex. *Mammal Review*, **21**, 51-65.

Sleeman, D.P. (1992) Long-distance movements in an Irish badger population. In: *Wildlife telemetry: remote monitoring and tracking of animals* (eds I.G. Priede & S.M. Swift), pp. 670-676. London: Ellis Harwood.

Smal, C. (1995) *The badger and habitat survey of Ireland.* Dublin: The Stationery Office.

Staines, B.W. & Ratcliffe, P.R. (1987) Estimating the abundance of red deer (*Cervus elaphus* L.) and roe deer (*Capreolus capreolus* L.) and their current status in Great Britain. *Symposia* *of the Zoological Society of London*, **58**, 131-152.

Stewart, P. D., Anderson, C., Macdonald, D.W. (1997) A mechanism for passive range exclusion: Evidence from the European badger (*Meles meles*). *Journal of Theoretical Biology* **184** (3), 279-289.

Strachan, R. & Jefferies, D.J. (1996) *Otter survey of England, 1991-1994.* The Vincent Wildlife Trust, London.

Sutherland, W.J. (1996) *Ecological census techniques - a handbook.* Cambridge: University Press.

Tapper, S. (1992) *Game heritage: an ecological review from shooting and gamekeeping records*. Fordingbridge: The Game Conservancy.

Thorburn, A. (1920) *British mammals*. London: Longmans, Green & Co.

Thornton, P.S. (1988) Density and distribution of badgers in south-west England - a predictive model. *Mammal Review*, **18**, 11-23

Usher, M.B. (1972) Developments in the Leslie matrix model. In Mathematical models in ecology (ed. J.N.R. Jeffers), pp. 29-60. Oxford: Blackwell Scientific Publications.

van der Zee, F.F., Wiertz, J., Ter Braak, C.J.F., van Apeldoorn, R.C. & Vink, J. (1992) Landscape change as a possible cause of the badger *Meles meles* L. decline in The Netherlands. *Biological Conservation*, **61**, 17-22

Vine, A.E. (1993) Norfolk badgers 1982-1992. *Transactions of the Norfolk and Norwich Naturalists Society*, **29**, 533-538.

Walsh, A.L., Harris, S. & Hutson, A.M. (1995) Abundance and habitat selection of foraging vespertilionid bats in Britain: a landscape-scale approach. *Symposia of the Zoological Society of London*, **67**, 325-344.

Walsh, A.L. & Harris, S. (1996a) Foraging habitat preferences of vespertilionid bats in Britain. *Journal of Applied Ecology*, **33**, 508-518.

Walsh, A.L. & Harris, S. (1996b) Factors determining the abundance of vespertilionid bats in Britain: geographical, land class and local habitat relationships. *Journal of Applied Ecology*, **33**, 519-529.

White, P.C.L. & Harris, S. (1995) Bovine tuberculosis in badger (*Meles meles*) populations in south-west England: the use of a spatial stochastic simulation model to understand the dynamics of the disease. *Philosophical Transactions of the Royal Society of London, series B*, **349**, 391-413.

Woodroffe (1992) Factors affecting reproductive succes in the European *badger (Meles meles*). D. Phil. thesis, University of Oxford

Woodroffe, G.L. & Lawton, J.H. (1990) Patterns in the production of latrines by water voles (*Arvicola terrestris*) and their use of indices of abundance in population surveys. *Journal of Zoology, London* **220**, 439-445

Woodroffe, R.W. & Macdonald, D.W. (1995) Female/female competition in European badgers Meles meles: effects on breeding success. *Journal of Animal Ecology*, **64**, 12-20.

Woodroffe, R.W., Macdonald, D.W. & da Silva, J. (1993) Dispersal and philopatry in the European badger, (*Meles meles*). *Journal of Zoology, London*, **237**, 227-239

Zar, J.H. (1996) *Biostatistical Analysis* (3rd ed.). Prentice Hall International.

11. Appendices

11.1 Instruction sheet describing how to record the badger data

GUIDELINES FOR RECORDING THE BADGER DATA

One of the maps has been divided into nine sub-squares. There is also a **Badger Data Sheet** on which is a sketch showing how each of these sub-squares is numbered one to nine, and underneath is a table on which you are asked to record whether you found: (a) footprints, (b) badger paths or runs and/or (c) dung pits in each of the nine sub-squares. All that is required is a simple yes or no.

Mark every sett you find on the same map, and denote each sett with a letter code that should be clearly shown on the map. If you find the same sett(s) as were present in the first survey, use the same letter code as for the first survey. Mark new setts with a new letter code to avoid any possible confusion. You should record every sett, even if it has been disused for a long time and is barely recognisable as an old badger sett. In such situations please also make some additional notes as to its state on the back of the **Badger Data Sheet.** A sett may be either a single hole or a series of a few or many holes. Sometimes two setts may be dug close together, when it may be difficult to decide whether you are looking at one sett or two. Basically, if you think all the holes are or could be interconnected underground, then it is one sett. There can be exceptions. For instance, setts dug in the banks on either side of a shallow ditch may have two separate series of holes on each side of the ditch with no underground connection. However, the entrance holes are only a few feet apart, and clearly form one sett complex. In contrast two separate series of holes on either side of a deep railway cutting would count as two separate setts. As a rough guide, two discrete series of holes separated by at least 15 metres, or closer if separated by a major obstacle such as a steep ditch or a road, would be classified as two separate setts.

Once you have marked the sett on the map, record the following information on the **Badger Data Sheet:-**

a. **The number of well-used holes:** these are clear of any debris or vegetation, are obviously in regular use, and may or may not have been excavated recently.

b. **The number of partially-used holes:** these are not in regular use and have debris such as leaves and twigs in the entrance, or have moss and/or other plants growing in or around the entrance. Partially-used holes could be in regular use after a minimal amount of clearance.

c. **The number of disused holes:** these have not been in use for some time, are partially or completely blocked, and could not be used without a considerable amount of clearance. If the hole has been disused for some time, all that may be visible is a depression in the ground where the hole used to be, and the remains of the spoil heap, which may be covered in moss or plants.

Please also record for each sett any signs of disturbance, in particular evidence of hole blocking by children or more serious attempts to block holes by e.g. landowners, sett stopping by hunts, etc., evidence of snaring around the sett, and any evidence of digging at the sett. A succinct precis of the extent and nature of any disturbance, and in particular your assessment as to the cause, will allow us to quantify the level of disturbance. It is particularly important that you differentiate between holes that have just been blocked and setts that have been dug by badger diggers. If you are in any doubt, a photograph will help us interpret your field notes, which in any case should be as comprehensive as possible.

11.1 continued

Finally, when the complete square has been surveyed, you should assign each sett to one of the following categories. This may be difficult, but is important, since by recognising and counting the number of main setts we can get an idea of the number of badger social groups in a particular type of habitat. As a guide to classifying each sett the following rules should be useful:-

a. **Main setts:** these usually have a large number of holes with large spoil heaps, and the sett generally looks well-used. There will be well used paths to an from the sett and between sett entrances. Although normally the breeding sett and in continuous use, it is possible to find a main sett that has become disused due to excessive digging or some other reason; it should be recorded as a disused main sett. In the first survey, the average size of an active main sett was twelve holes *(including all categories of use).*

b. **Annexe setts:** these are often close to a main sett, usually *less than 150 metres* away, and are usually connected to the main sett by one or more obvious well-worn paths. They usually have several holes, but may not be in use all the time even if the main sett is very active. In the first survey the average size was five holes (including all categories of use).

c. **Subsidiary setts:** these often only have a few holes; four (including all categories of use) was the average number in the first survey. They are usually at least 50 metres from a main sett, and do not have an obvious path connecting with another sett. They are not continuously active.

d. **Outlying setts:** these usually have only one or two holes, often have little spoil outside the hole, have no obvious path connecting with another sett, and are only used sporadically. When not in use by badgers, they are often taken over by foxes or even rabbits. However they can still be recognised as badger setts by the shape of the tunnel (not the actual entrance hole), which is usually at least 250 mm in diameter, and is rounded or a flattened oval shape. Fox and rabbit tunnels are smaller and often taller than broad.

These categories sound clear cut on paper, but in the field it may be difficult to place a sett in a particular category. In areas of low badger density main setts may be small, only a few holes, and in moorland and hill areas main setts may consist of only one or two entrances in a rocky cairn. Also do not expect to find an example of every type of sett; many badger social groups will not have an annexe sett, and many badger groups simply have a main sett and several outliers. In a poor badger habitat you may search a large area and still fail to find a main sett. So your decision on how to classify each sett may not be easy, and it is important that you have an overall view of all the setts in the area before you make a decision. So search the whole square before you start to classify the setts. If you find no setts or a large, very obvious main sett, then your decision is easy, and you need to do no more searching. However, if you are still in doubt, it may be necessary to extend your search for setts beyond the selected one kilometre square. However, it will rarely be necessary to go more than 500 metres into an adjacent square, and usually you will not need to go so far. It will be clear from your initial detailed search of the selected one kilometre square where most of the badger activity occurs, and so you only need search parts of those square(s) adjacent to the area of most badger activity. If you do have to move into nearby square(s) only search the minimum area needed for you to interpret your findings from the selected square. Indicate the additional areas you searched on the same map as you marked the setts. Do not record any habitat data from the additional area searched, but mark any additional setts on the map, and document the same information as with the badger setts within the square.

11.2 Badger data recording sheet

BADGER DATA SHEET FOR SQUARE NO.

Date of survey:- Recorder(s):-

The nine squares on map 1 are numbered as shown below:-

7	8	9
4	5	6
1	2	3

For each of these nine squares, please record the presence or absence of the following:-

	Footprints	Paths or runs	Dung pits
Square 1			
2			
3			
4			
5			
6			
7			
8			
9			

For each sett, please record:-

	No. of well-used holes	No. of partially-used holes	No. of disused holes	Evidence of hole blocking	Evidence of snaring	Evidence of digging	Category of sett
Sett A							
Sett B							
Sett C							
Sett D							
Sett E							

If necessary, please continue on the reverse side of this sheet or on an additional sheet of paper. In particular make detailed notes on any digging, snaring, blocking or other form of disturbance at each sett on the back of this sheet, making it clear which sett is being referred to and the source of any disturbance.

11.3 Instruction sheet describing how to record the habitat data

GUIDELINES FOR RECORDING THE HABITAT DATA

Please record the habitat data on the map without the red squares drawn on it. This is a copy of the most up-to-date 1:25,000 map and has been enlarged several times. However, be aware that fields may have been merged, roads built, hedgerows removed and woods partially or completely felled since the revision. These changes will need to be marked on the map. All the habitat types have been numbered and described below; all you need to do in the field is first of *all mark surviving hedgerows in one bright* colour and treelines in another. Then use as many different colour pens as possible to mark the boundary of each field or habitat type. On the reverse of the map simply use the numbers from the list below to identify which colour has been used to code for which habitat type. Although there are many habitat types listed below, in most one kilometre squares you will use less than half a dozen of these categories, so the task should not be too complex. Also do not try to record every minute piece of, for example, bracken. Only mark on the map habitats at least 50 metres length or 500 square metres in area.

1. **Hedgerows**: less than 4 metres high and less than 5 metres wide. Classify them as continuous if the gaps are less than 10 metres wide.
2. **Treelines**: a line of single trees (minimum of three) greater than 4 metres high and less than two canopy widths apart. Hedgerows may be associated with treelines.
3. **Semi-natural broadleaved woodland**: predominantly broadleaved trees more than 5 metres high with a semi-natural or natural growth.
4. **Broadleaved plantations**: tree species not native to the site and of even age.
5. **Semi-natural coniferous woodland**: predominantly coniferous trees of any height with semi-natural or natural growth.
6. **Coniferous plantations**: predominantly coniferous trees which have been planted.
7. **Semi-natural mixed woodland**: at least 25% broadleaved and 25% coniferous trees with semi-natural or natural growth and trees over 5 metres high.
8. **Mixed plantations**: at least 25% broadleaved and 25% coniferous trees, planted.
9. **Young plantations**: young trees, up to 3 metres high, both coniferous and broadleaved, which have been planted.
10. **Recently felled woodland**: areas for which there is evidence that woodland has been felled recently.
11. **Parkland**: areas where the tree cover is less than 30%, the majority of the trees between 30 and 70 metres apart, and a minimum number of ten trees.
12. **Tall scrub**: between 3 and 5 metres high. N.B. stands of trees less than 5 metres high should be classified as woodland, not scrub.
13. **Low scrub**: bushy vegetation less than 3 metres high.
14. **Bracken**: land dominated by bracken with at least 75% cover.
15. **Coastal sand dunes**: include all stages of succession where the vegetation is grass-dominated or wet dune slacks.
16. **Coastal sand or mud flats**: should be fairly obvious.
17. **Coastal shingle or boulder beaches**: should be fairly obvious; include outcrops of bare rock on foreshores.
18. **Lowland heaths**: lowland areas with at least 25% dwarf shrubs.
19. **Heather moorlands**: as above but for upland sites.
20. **Blanket bog**: areas of peat with the vegetation dominated by heather.
21. **Raised bog**: at least half the peat area raised into a shallow dome.

22. **Marginal inundation**: swamps or fens but not coastal marshes.

23. **Coastal marsh**: predominantly salt marsh vegetation.

24. **Wet ground**: areas of wet land found in association with other habitats e.g. wet areas in a grassland field or flushes in upland areas.

25. **Standing natural water**: ponds and lakes with no evidence of damming.

26. **Standing manmade water**: artificially created reservoirs and impoundments.

27. **Running natural water**: ditches, streams and rivers with no evidence of canalisation.

28. **Running canalised water**: a water course that has been confined to flow in a certain direction by man.

29. **Upland unimproved grassland**: in upland areas, and will include some areas used for rough grazing and poor quality grassland such as purple moor grass. They have not been improved by the application of fertilisers, herbicides or by drainage.

30. **Lowland unimproved grassland**: may be regularly grazed or mown, but may be totally neglected. Should not have been improved by the application of fertilisers or herbicides to significantly alter the composition of the sward. This includes herb-rich grasslands on downland, cliff tops, etc.

31. **Semi-improved grassland**: grassland which has been slightly modified by fertiliser or herbicide application, or by heavy grazing pressure and/or drainage.

32. **Improved grassland**: grassland that has had regular treatments of artificial fertilisers and herbicides. N.B. this should not include monoculture grassland i.e. grassland leys (see 33).

33. **Arable**: all classes of arable land, include grassland leys and horticulture. A grassland ley is defined as short-term grassland, and will usually have been re-seeded less than five years previously. It is characterised by evidence of ploughing, bare soil between the grass plants, a scarcity of broadleaf plants, and is usually dominated by a single grass species, often rye grass. There are usually less than 5-10 species per square metre. Category 32 consists of longer term grassland with a high density of grass and broadleaf species, usually in enclosed land.

34. **Amenity grassland**: this includes well maintained non-agricultural grass, such as playing fields, recreation grounds and golf courses.

35. **Unquarried inland cliffs**: unvegetated rock over 5 metres in height and at an angle of at least 60^{o}. It includes scree.

36. **Vertical coastal cliffs**: as above but in coastal areas and mostly unvegetated.

37. **Sloping coastal cliffs**: at an angle of less than 60^{o} and mostly vegetated.

38. **Quarries and open-cast mines**: any excavation (gravel pits, chalk pits, etc.), including unvegetated spoil heaps.

39. **Bare ground**: bare soil or ground not covered by vegetation and which does not fall into categories 35-38.

40. **Built land**: any urban areas including gardens and transport corridors. Will include road and motorway verges. For this category do not bother to mark built up areas, roads, etc. on the map unless there has been some change since the map was printed, when it should only be necessary to mark the changes.

RECORDING CHANGES TO THE BADGER SETTS

The most difficult part of the survey is to accurately document any changes that may have occurred during the nine years between the two surveys. Yet this is clearly the most important part of the whole exercise, so please take a great deal of care in recording any changes that you think may have occurred. For most squares, it will be easy; during the first survey 71.5% of all the squares surveyed had no setts in them at all, and it is unlikely that there will have been any change in most of these. However, you must still survey these squares very carefully to check that no setts were missed the first time around, or that no new setts have been dug in the last few years. *So it is important that you check negative squares just as carefully as squares that contained a sett on the first survey.*

There are a number of reasons why things may be different between the two surveys:-

a. **The data were incorrectly recorded on the first survey.** This may be because a sett was missed or because its status was incorrectly assessed. However, before you jump to any conclusions, you must check all the available options. Was the sett really missed, or has it been dug in the *intervening years?* Large, well-established setts that may look very old can be quite new or may be a recently enlarged fox earth. So *do not jump to a hasty* conclusion; if in doubt the farmer, landowner, gamekeeper or shooting tenant may be able to help. *If you think that a mistake was* made on the first survey, fully document your reasons for making this assessment on the **Changes Data Sheet.**

b. **The status of a sett has changed.** A sett may still be present in the same position as before but it has significantly increased or decreased in activity, and as a consequence its status has changed. If you think that the status is different to that assessed on the original survey, but that the original assessment was correct, explain why you have come to this conclusion on the **Changes Data Sheet.**

c. **A sett has completely disappeared or ceased to be a badger sett.** It can often be difficult to be sure that a sett has disappeared, especially if its position was not mapped accurately during the first survey. Equally, it can be difficult if all you find are some rabbit or fox holes where you expected to find a badger sett. Are the rabbit or fox holes all that remains of the sett that was correctly documented last time or was an error made during the first survey? If it was a sett that has been abandoned, the spoil heaps should still be visible even after several years. If you think that the sett has been abandoned, try to determine why this might have occurred - e.g. a new sett may have been dug nearby, the sett may have been repeatedly disturbed and eventually abandoned, a change in the pattern of land use may have made the site less desirable, etc. Record your conclusions on the **Changes Data Sheet.** If a sett has completely disappeared, this may also have occurred for a number of reasons, such as land use changes (the removal of a piece of woodland or hedgerow), new road schemes, building developments (either residential or industrial), recreational schemes such as golf courses, or it may have been lost due to excessive digging. When a sett has disappeared, try to determine the factors that have led to the loss and give a detailed summary explaining why you have come to that conclusion. Also, document any remnants of the sett that you might be able to locate.

d. **A new sett has appeared.** This may be a sett that has been dug from scratch, or a rabbit warren or fox earth that has been enlarged and taken over by the badgers. To help you confirm that it is a new sett, the farmer, landowner, gamekeeper or shooting tenant may be able to advise you. Remember that size is not everything; large, well-established setts can be quite new. When you have decided that a sett has been established since the last survey, explain why you have come to this conclusion on the **Changes Data Sheet.**

It is obviously important that you sort out which of these reasons apply to any change(s) that you observe; to help us analyse the results, we need as full a report as possible. So please be as clear and as accurate in your assessment as possible. A **Changes Data Sheet** is supplied to document your observations, but please use additional sheets as necessary, and make it clear which sett is being referred to in each report. Finally, if you observe any changes, please add your telephone number to the **Changes Data Sheet,** so that we can telephone you if we need to clarify anything.

11.5 Data sheet for recording badger sett changes

CHANGES DATA SHEET FOR SQUARE NO.

Recorder(s):-

Did you record any changes to the status or presence of
the badger setts documented in the first survey: Yes/No

If the answer is yes, please complete the rest of the information on this sheet.

Work telephone number: Home telephone number:

Details of the data you think were incorrectly recorded on the first survey:-

Details of the setts you think have changed in status:-

Details of the setts which have completely disappeared or ceased to be a badger sett:-

Details of the setts which have appeared since the last survey:-

Please give as much information as possible, and continue on the back of this sheet or on additional sheets as necessary.

11.6 Choosing the survey design

11.6.1 The survey design

The primary aim of the 1980s survey was to provide a baseline against which any future changes in badger numbers could be assessed (Cresswell, Harris & Jefferies, 1990). Although changes in badger numbers can occur either through changes in the number of social groups or in the size of social groups, a change in the number of social groups is more likely to reflect long-term trends in the population. It was accordingly most important that the survey protocol detected number changes in the number of badger social groups accurately. In this section the underlying rationale for the survey is discussed

There are two key problems that need to be met by a national monitoring scheme: how can the population be sampled representatively, and how many samples are required? The power of the monitoring scheme depends on these factors. Sampling must be random, to produce anreliable and unbiased result (Krebs 1989). Sutherland (1996a) lists "not sampling randomly" as the first of twenty censusing sins, and the value of random sampling is also discussed by Cochran (1963), Magurran (1988) and Greenwood (1996), who also stress the value of stratified sampling. The 1980s badger survey used a stratified random approach. The 1-km squares were allocated to 32 strata reflecting similar patterns of land use, geology, climate, etc. using the Institute of Terrestrial Ecology's land classification scheme (section 1.4.1), and within these strata the 1-km squares to be surveyed were selected at random. Stratified sampling allows population size to be estimated with greater accuracy than with non-random sample selection. [Using the data from the 1980s badger survey, Greenwood (1996) provided a worked example to demonstrate that the confidence limits for the population estimate are half that which would have been achieved without stratification]. The value of using a stratified sample to reduce the confidence limits on the population estimate was also stressed by Cresswell, Harris & Jefferies (1990).

Stratification is of particular benefit for surveys of populations that are heterogeneously distributed, so long as the strata are relatively homogeneous. Under these circumstances, there is a substantial gain in the precision of the population estimate when compared with simple random sampling. To illustrate this, the 1980s data on main setts was used to compare the size of the 95% confidence intervals with a random survey, with the sample divided into the seven land class groups, and the 32 land classes.

The 95% confidence intervals are calculated for a random survey as follows:-

$$t_{0.05}s/\sqrt{n}$$

where s is the standard deviation, n the number of 1-km squares and $t_{0.05}$ is the value of t at probability 0·05, for degrees of freedom of n-1.

For a stratified sample, the 95% confidence intervals are calculated as follows:-

$$t_{0.05}(W_h^2S_h^2/n_h)$$

where n_h is the number of 1-km squares in stratum h, W_h^2 is the stratum weight i.e. the total number of 1-km squares surveyed in that land class group divided by the total number of 1-km squares in the land class group, and S_h^2 is the stratum variance.

When these formulae were applied to the 1990s data (see summary in Table 3.12), the population estimate and the 95% confidence intervals for the number of badger social groups in Britain were 55,787±5192 social groups without stratification, 50,241±4327 social groups with the sample stratified into the seven land class groups, and 50,850±4580 social groups with the sample stratified into 32 land classes.

The population estimate without stratification was obtained simply multiplying the mean number of main setts per 1-km square in Britain by the area of rural land. This gave higher 95% confidence intervals than with a stratified sample. However, the 95% confidence interval was not much greater than when the sample was stratified. This is because although no stratification correction was used in the calculation, approximately 1% of each land class was surveyed, and so all land classes contributed approximately equally to the population estimate. Had the 2271 1-km sample squares been selected completely at random, the 95% confidence intervals undoubtedly would have been larger. [The actual population estimate with this approach is also quite a bit larger because no allowance was made for the different areas of each land class, and the higher density areas of southern Britain were sampled more intensively than some of the lower density areas in the north (see Figure 2.1).]

The estimates produced when the sample was stratified using the seven land class groups and the 32 land classes are very similar, both in terms of the total population estimate and the 95% confidence intervals, with the seven land class groups producing a slightly lower 95% confidence interval. Whilst using a lower level of stratification should have produced the opposite result, this result probably reflects the fact that very few squares were sampled in some of the smaller land classes, and they therefore had a large standard error. In contrast, the seven land class groups all have large sample sizes, and hence smaller standard errors, thereby producing a lower 95% confidence interval overall. This result is also probably in part a consequence of the Institute of Terrestrial Ecology grouping similar land classes together (see section 1.4.1), thereby reducing the variability in the badger data within each land class group. Hence this result is a reflection of the robustness of their land class groups. Therefore the analyses of the data were carried out by these land class groups.

Some potential variability within each stratum was also excluded by not surveying 1-km squares that were largely urban. There were two reasons for this. First, badgers are rare in urban habitats (Harris, 1984; Cresswell, Harris & Jefferies, 1990), and so monitoring changes in a small number of social groups would not be possible with a national survey such as this. Also, including large areas of urban land in the survey would further skew the data toward zeros because urban 1-km squares are very unlikely to contain badgers. An underlying assumption of the Poisson and negative binomial distributions is that each 1-km square included in the survey must at least have the potential to contain a badger sett. This is not true for many urban 1-km squares, and so their inclusion in the survey would further complicate the statistical basis of the analyses.

Predicting the number of 1-km squares that should be monitored to reflect changes is less easy. Cresswell, Harris & Jefferies (1990) showed that a stable mean population estimate for all but the lowest density of the 32 land classes was achieved with a sample of around 30 1-km squares, and so it was only necessary to survey around 1000 1-km squares to provide a reliable population estimate. Deciding on a database that can persist for an extended period, as is required for an effective monitoring system, is a lot harder, and there are no clear guidelines to help with this process. It is impossible, for instance, to predict the rate of attrition from the database due to refused access to land, the loss of 1-km squares due to urbanisation and other developments, and the future distribution of surveyors to repeat the exercise. Thus, in the 1980s survey, Cresswell, Harris & Jefferies (1990) aimed to achieve the largest coverage possible, whilst at the same time maintaining an even distribution of 1-km squares both regionally and by habitat types.

This survey was designed as a monitoring exercise, and as such the aim was to measure real change in both the number of badger social groups and badger numbers in a random sample of 1-km squares stratified to represent each region and pattern of land use in Britain. The problems of monitoring population change are discussed in various papers in the volume edited by Sutherland (1996b). The 1980s survey data was used to determine which is the best survey design for a monitoring programme and, in particular, compare the benefits of surveying the original 1-km squares again or taking a new random sample of 1-km squares. These analyses were carried out by the seven land class groups.

The main questions considered were:-

a. How big must any changes in the number of badger social groups be before we can detect them?

b. How good is the sampling regime?

c. Is a repeated design best for monitoring change in Britain's badger population?

Four basic approaches were used to answer these questions:-

a. Firstly, the distribution of main setts were examined, and the effect of this on the confidence intervals of our estimates.

b. The confidence intervals were then examined and the effect of sample size on the estimates.

c. The confidence intervals were then used to compare the effectiveness of resurveying the same 1-km squares as opposed to surveying a new random sample of 1-km squares for detecting change in the badger population.

d. We then describe the statistical analyses used to detect the changes observed between the surveys, based on surveying the same 1-km squares again.

11.6.2 The underlying badger distribution - random or clustered?

It is important to consider the underlying distribution of badger main setts because this could affect the confidence intervals for the estimates of the population of social group number in the land class groups. Smal (1995) examined these data from the 1980s in Britain and found that overall they followed a negative binomial distribution. This distribution is found when sampling a population which is aggregated, and is common when dealing with wildlife. In the Republic of Ireland, however, Smal (1995) found that the distribution of main setts was less clumped and fitted a Poisson distribution, indicating a more random distribution.

The pattern of distribution of main setts in Britain was examined by land class group. The geographical distribution of plants or animals may be uniform, random, or aggregated, and the pattern of distribution determines the best survey design. Of the three patterns of distribution, badger main setts would have a uniform distribution when all habitats were equally suitable, and all territories were occupied. Thus there would be a constant, minimum, distance between main setts (see Kruuk, 1978). If this was the pattern of badger distribution, surveying would be easy, and a small sample of 1-km squares would provide an accurate population estimate with small confidence intervals. For a territorial species such as the badger, a random distribution would be unlikely to occur naturally unless patches of suitable habitat were both small and fragmented, so that generally only a single social group of badgers occupied each habitat patch. However, anthropogenic influences, such as persecution leading to the loss of social groups from areas with suitable habitat, could also lead to a random pattern of distribution.

An aggregated pattern of distribution occurs where badger setts, in this case, are clumped i.e. there is a greater probability of locating a second sett once one has been found. That undoubtedly will be the case for the smaller categories of sett, because they are only found within a territory and hence in the vicinity of each other and also a main sett. However, if it is the case that main setts are also aggregated, it means that there is a greater probability of finding main setts close to each other. This will occur if patches of suitable habitat are fragmented but large enough to hold several badger territories and/or if the natural pattern of distribution has been disrupted by persecution or other anthropogenic factors.

The first step to identifying an aggregated distribution is the variance-to-mean ratio. If this value is greater than 1, the data show evidence of aggregation. The larger this value is above 1, the more clumped are the data. This index is especially useful for examining the main sett data because it is only weakly affected by density (Krebs, 1989). It was found that the main sett data for five land class groups (Arable I, Arable II, Pastoral IV, Pastoral V and Marginal upland VI) had a variance-to-mean ratio greater than 1, and a negative binomial distribution best described the distribution of main setts in these five land class. Whilst the distribution of main setts was aggregated in these five land class groups, this was most pronounced in Pastoral IV and Marginal upland VI, whereas Arable I was the least clumped. So whilst Arable I and Pastoral IV had similar mean main sett densities in the 1980s (0·47 and 0·42 main setts km^{-2} respectively), their underlying distributions may be different.

For two land class groups (Arable III and Upland VII) the variance-to-mean ratio was equal to one, indicating that in these land class groups 1-km squares containing main setts are best described by a random distribution. This does not mean that environmental factors are not affecting their distribution, but is probably at least in part a reflection of the rarity of main setts in these land class groups (0·10 and 0·01 main setts km^{-2} respectively). The rarity of setts is not in itself a complete explanation, since the density of main setts in Marginal upland VI was also only 0·10 km^{-2}, yet here the distribution was aggregated.

11.6.3 Detecting changes in the density of badger main setts in the land class groups

The effects of sample size on the estimates of main sett density were examined. For this, I calculated the mean number of main setts per 1-km square from a random sample of 25, 50, 100, 200, 300, 400 and all the 1-km squares from each of the seven land class groups (Figure 11.6.1). It can be seen that with a sample size of 50 or fewer 1-km squares, the mean density estimate is highly variable, and for most land class groups, a sample of 200 or more 1-km squares is needed before the mean main sett density remains constant. Thus, our samples within each land class group are adequate for estimating badger population densities.

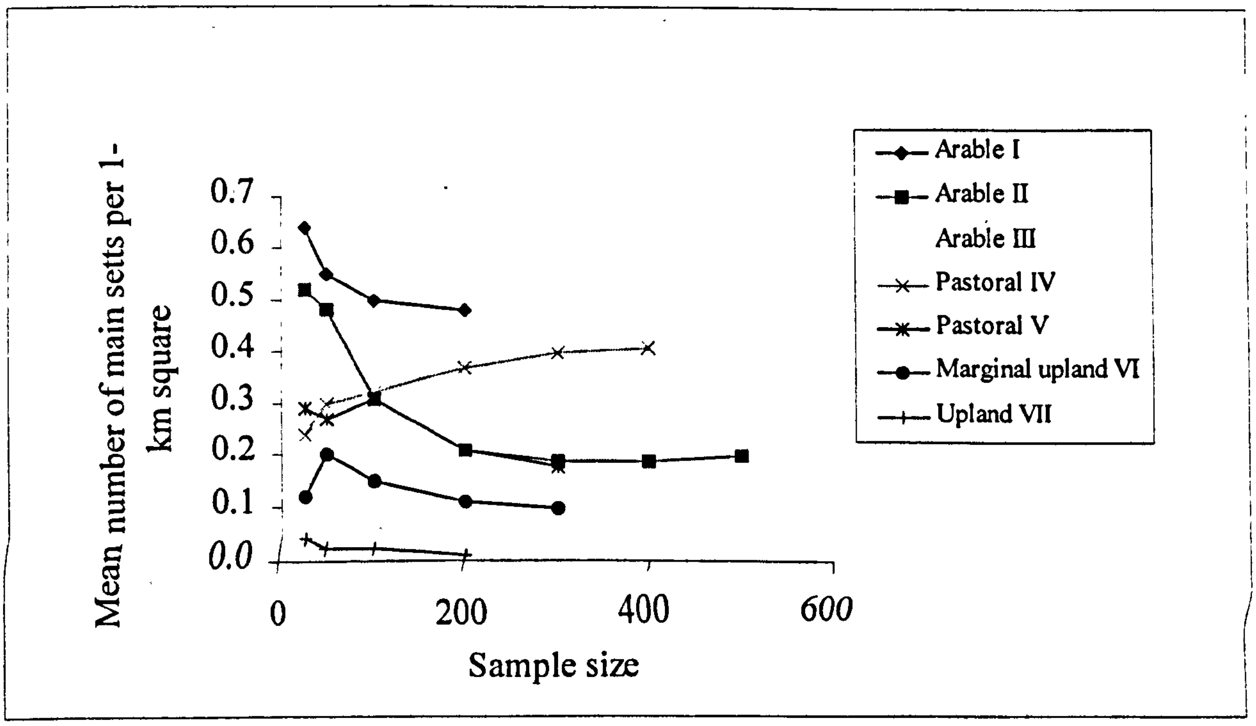
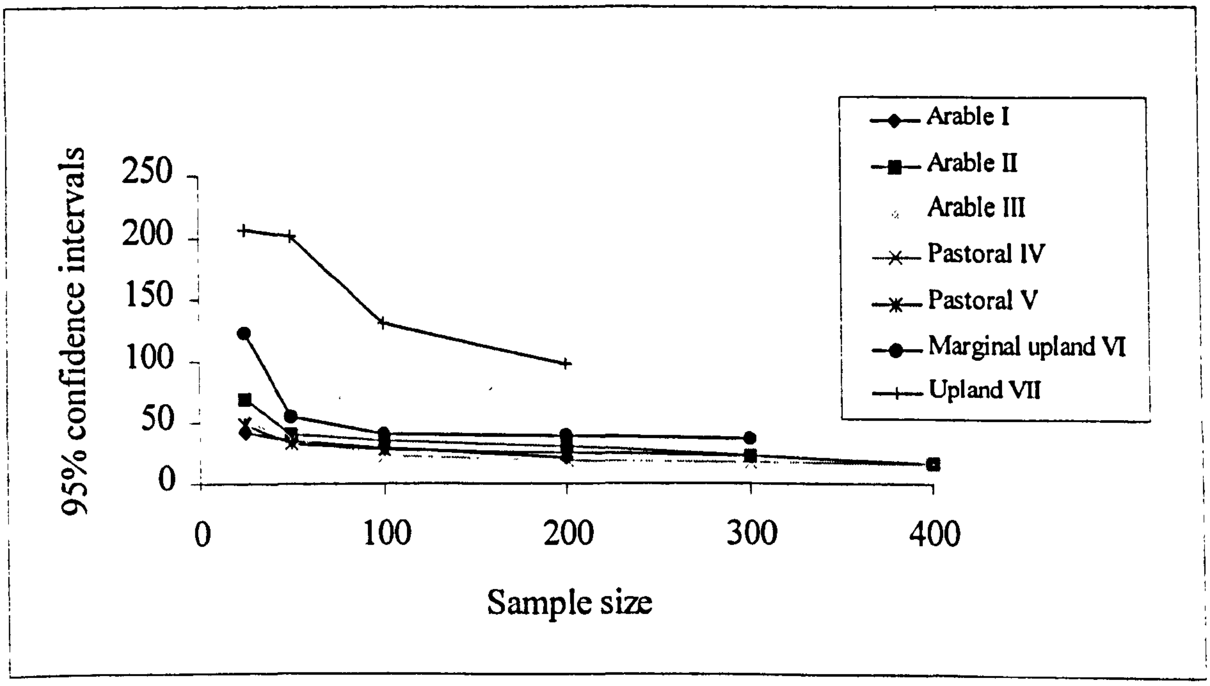


Figure 11.6.1 The effects of sample size on the estimated mean main sett density km^{-2} in the 1980s for the seven land class groups.

How the 95% confidence intervals varied with increasing sample sizes was examined, based on the standard errors of the means of sub-samples. From Figure 11.6.2, it can be seen that with a small sample size, the confidence intervals were extremely large but, as expected, they decline in size rapidly as sample size increases, particularly for the land class groups with lower badger density. However, irrespective of badger density, increasing the sample size above 100 1-km squares per land class group has little impact on the size of the confidence intervals. For instance, for land class group Pastoral V, the 95% confidence interval is ±23% with a sample size of 333 1-km squares; more than doubling the sample size to 700 1-km squares would only reduce the 95% confidence intervals to ±18%. Figure 11.6.2 also shows that with badger densities above about 0·15 main setts km^{-2}, as occurs in land class groups Arable I, Arable II, Pastoral IV and Pastoral V, increasing badger density does not affect the 95% confidence intervals for any given sample size, and that the 95% confidence intervals for land class groups Arable III and Marginal upland VI, with mean densities of 0·10 main setts km^{-2}, are very similar. Only the land class group Upland VII, with a mean density of 0·01 main setts km^{-2}, had substantially higher 95% confidence intervals for any given sample size. Therefore, the sampling regime is robust and samples most badger densities equally effectively.



11.6.2 The effects of sample size and badger population density on the 95% confidence intervals of the mean population estimate.

11.6.4 Designing a repeat survey that maximises the chance of detecting change

Because the distribution of badger main setts is clumped in most land class groups, the 95% confidence intervals are quite large, even when both the mean density of main setts and the sample sizes are large. For example, in land class group Arable II, almost 500 1-km squares were surveyed but the 95% confidence interval is ±16% of the mean value. The 95% confidence interval for the overall estimate of number of social groups in the 1980s was ±9% (Cresswell, Harris & Jefferies, 1990) because of the large sample size and because stratified samples produce narrower population confidence intervals.

Because of the clumped distribution of badger main setts, and the effect this has on the 95% confidence intervals of the mean density estimates for each land class group, taking a new random sample of 1-km squares for the repeat survey would cause significant practical problems. Whilst the mean density estimates might vary between the two surveys, the large confidence intervals would require a population change of at least 25% in land class groups Arable I, Arable II, Pastoral IV and Pastoral V for this to be statistically significant, and any smaller population changes, or larger changes in lower density land class groups, would not be statistically significant.

This problem is best overcome by taking a repeated sample from the same 1-km squares (Cochran, 1963); the two surveys are then highly correlated and small differences between the two samples, therefore, represent real change (Cochran, 1963). This is because the variance of the estimated change in main sett density for a repeated survey is equal to:-

$$S_1^2 + S_2^2 - 2rS_1S_2$$

where S^2 is the variance of samples 1 and 2, S is the standard deviation of samples 1 and 2 and r is the correlation coefficient between samples 1 and 2. For two independent samples however the estimated change has a variance of:-

$$S_1^2 + S_2^2$$

This will be greater because, as r approaches 1, the variance of the estimate of change for the repeated sample declines (Cochran, 1963). This means that for almost all types of survey, the variance of the estimate of change will be less with a repeated design, and so a repeated design provides considerably greater analytical power given the nature of the data.

Hence a repeated sample survey design is chosen because in addition to producing patterns of real change in the sample squares, it gives the best chance of detecting change overall in Britain's badger population. This approach also has the considerable advantage that it is possible to monitor the pattern of change as well as the magnitude of change i.e. the fate of individual setts can be followed and any changes in sett size and status quantified. It also enables subtle changes to be detected. For instance, setts may be lost but replaced by others; the absence of overall numerical change would then mask significant local changes within the badger population, when such 'churning' occurs. Such changes will only be detected by repeatedly surveying the same 1-km squares. Finally, where setts are lost, reasons for their disappearance can be determined and used to predict future patterns of population change.

However, whilst resurveying the same 1-km squares has significant advantages for a monitoring programme such as this, there are still practical problems with deciding what is real change, especially when relying just on changes in the number of main setts. The problems are in large part due to the aggregated nature of the data, and because most 1-km squares had no main setts, and very few had more than one. Thus a large number of 1-km squares have to be surveyed within each land class group before real population changes can be detected reliably. The problem is illustrated in Figure 11.6.4, which shows the percentage change in mean main sett density that can be detected with different sample sizes at different badger population densities. With only 100 1-km squares sampled per land class group (which would have given reasonably good population estimates and 95% confidence intervals), only large changes in the number of social groups can be detected, even at the highest badger population densities. Even with 1000 1-km squares sampled, population changes of less than 20% could only be detected in the highest density land class groups. Surveying 1000 1-km squares in each land class group would not be logistically possible. However, the large increase in effort that would be required offered only a small increase in ability to detect change over the sample sizes we already have. So a reasonable balance between what is feasible and the "ideal" sample size to detect population changes has been achieved. Figure 11.6.3 illustrates the percent change in mean main sett densities that can be detected at different levels of significance with the survey data.

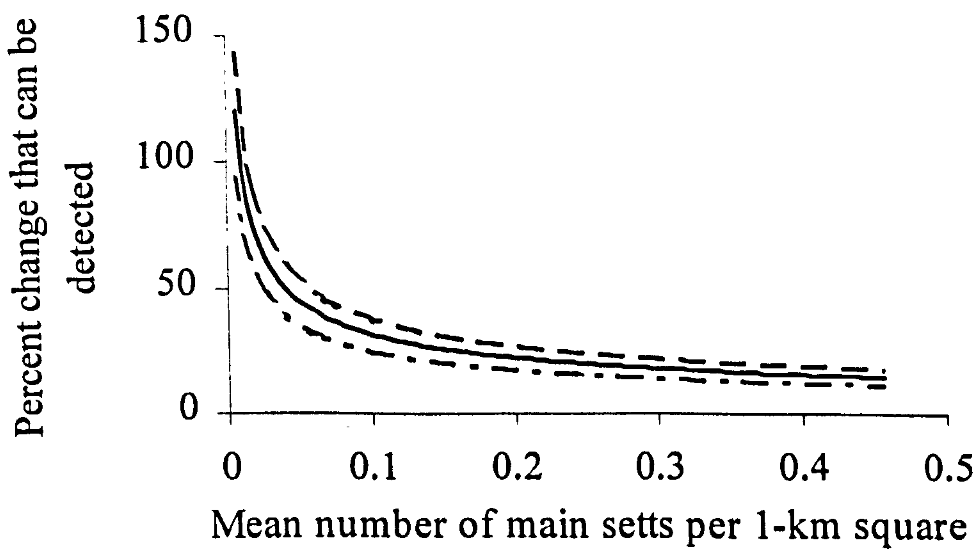


Figure 11.6.3 The percent change in the number of badger social groups that can be detected at different population densities at different levels of statistical significance. The lines are best fits through the sample sizes for each land class group in this survey. The lines indicate, from the top, $p<0{\cdot}01$, $p<0{\cdot}05$ and $p<0{\cdot}1$

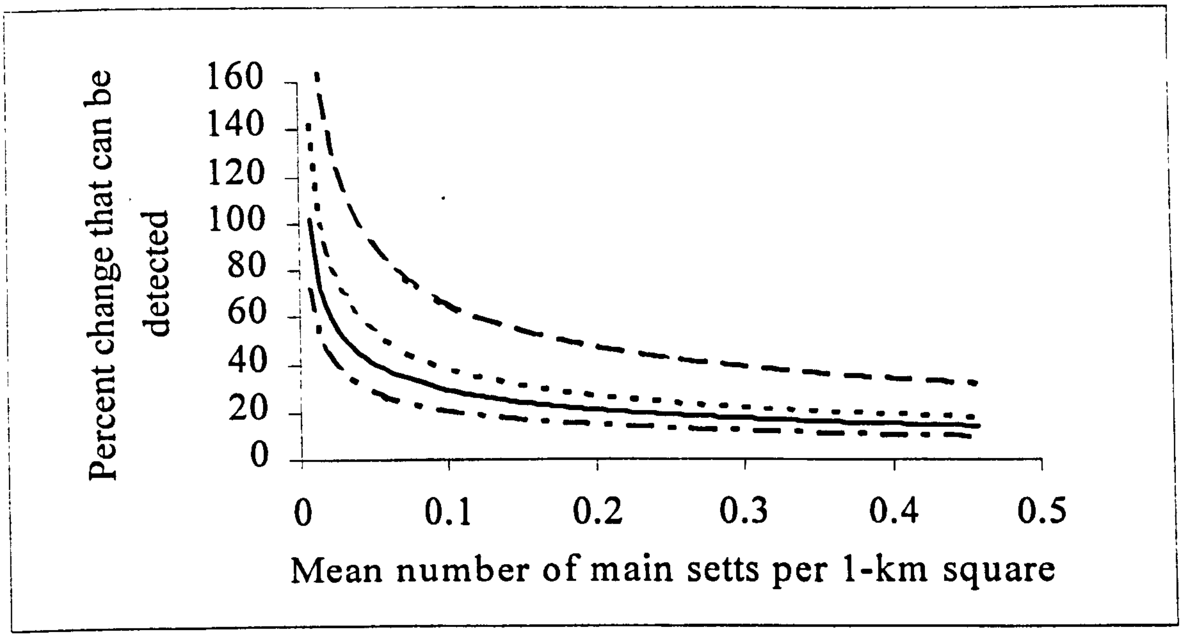


Figure 11.6.4 The percent change in the number of badger social groups that can be detected (p<0·05) at different population densities with various sample sizes. The lines indicate, from the top, samples of 100 1-km squares, this surveys' sample sizes, 500 1-km squares, and 1000 1-km squares.

Both these graphs demonstrate that problems with sample sizes and our ability to detect change which is statistically significant remain roughly constant over a wide range of badger population densities, but that the limitations of any sampling protocol rise dramatically below densities of 0.1 main setts km^{-2}. At such low densities, it would be extremely difficult to detect even quite large population changes with any degree of statistical significance, however many 1-km squares were surveyed, if we relied solely on changes in the number of main setts. However, this problem is in part addressed by using a wide variety of measures of change (the total number of setts, changes in levels of activity at setts, the ratio of annexe to main setts and field signs). These different measures all provide additional evidence of any existing trends in population change, even given a lack of statistically significance in the differences in numbers of social groups in any given region or land class group. Also, due to the intransient nature of badger setts, any trends observed are true for the repeated survey squares.

11.6.5. Determining the significance of the observed change

Having decided that a repeat survey is the best approach, the next problem is to decide how to determine the level of significance of any population changes. For the badger data, the mean and the variance of any population changes are not the best measures for determining the significance of any observed change because these data are not normally distributed, and because the confidence intervals are so high. However, the paired survey design enables us to use paired tests to determine the significance of any observed changes; in this thesis I use the Wilcoxon matched pairs test, which is a non-parametric analogue of the paired *t*-test, and 95% as powerful (Zar, 1984). For this, the data from just the 2271 1-km squares that were included in both surveys were used.

11.7 Changes in the number of annexe, subsidiary, outlying and disused main setts, 1988-1997

Table 11.7.1. The change in the number of annexe setts, 1988-1997, by land class group.

Land class group	Number of squares	Number of annexe setts in the 1980s	Number of annexe setts in the 1990s	Percent change	Significance
Arable I	208	53	92	74	$p<0{\cdot}001$
Arable II	493	45	72	60	$p<0{\cdot}05$
Arable III	188	2	8	-	-
Pastoral IV	428	82	157	91	$p<0{\cdot}0001$
Pastoral V	333	30	41	37	n.s.
Marginal upland VI	335	8	29	-	-
Upland VII	286	0	1	-	-
Totals	**2271**	**220**	**400**	**82**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.2. Regional changes in the number of annexe setts, 1988-1997.

Region	Number of squares	Number of annexe setts in the 1980s	Number of annexe setts in the 1990s	Percent change	Significance
North England	170	6	6	-	-
North-west England	72	5	8	-	-
North-east England	121	14	7	-50	n.s.
West Midlands	177	19	70	268	$p<0{\cdot}0001$
East Midlands	153	12	17	42	n.s.
Central England	91	12	12	0	n.s.
East Anglia	161	7	11	-	-
South-west England	205	64	117	83	$p=0{\cdot}0001$
Southern England	131	21	43	105	$p<0{\cdot}01$
South-east England	159	24	41	71	$p<0{\cdot}05$
North Scotland	366	3	2	-	-
South Scotland	208	2	10	-	-
Mid and north Wales	143	12	28	133	$p<0{\cdot}01$
South Wales	114	19	28	47	n.s.
Totals	**2271**	**220**	**400**	**82**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.3. The change in the number of subsidiary setts, 1988-1997, by land class group.

Land class group	Number of squares	Number of subsidiary setts in the 1980s	Number of subsidiary setts in the 1990s	Percent change	Significance
Arable I	208	93	154	66	$p<0{\cdot}01$
Arable II	493	74	98	32	$p<0{\cdot}05$
Arable III	188	8	14	-	-
Pastoral IV	428	143	242	69	$p<0{\cdot}0001$
Pastoral V	333	67	89	33	$p<0{\cdot}05$
Marginal upland VI	335	38	49	29	n.s.
Upland VII	286	6	11	-	-
Totals	**2271**	**429**	**657**	**53**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.4. Regional changes in the number of subsidiary setts, 1988-1997.

Region	Number of squares	Number of subsidiary setts in the 1980s	Number of subsidiary setts in the 1990s	Percent change	Significance
North England	170	15	26	73	n.s.
North-west England	72	14	19	36	n.s.
North-east England	121	4	9	-	-
West Midlands	177	45	79	76	$p<0{\cdot}01$
East Midlands	153	21	24	14	n.s.
Central England	91	17	30	76	n.s.
East Anglia	161	8	18	-	-
South-west England	205	118	192	63	$p<0{\cdot}001$
Southern England	131	42	68	62	$p<0{\cdot}01$
South-east England	159	42	67	60	n.s.
North Scotland	366	12	11	-8	n.s.
South Scotland	208	16	13	-19	n.s.
Mid and north Wales	143	32	53	66	$p<0{\cdot}05$
South Wales	114	43	48	12	n.s.
Totals	**2271**	**429**	**657**	**53**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.5. The change in the number of outlying setts, 1988-1997, by land class group.

Land class group	Number of squares	Number of outlying setts in the 1980s	Number of outlying setts in the 1990s	Percent change	Significance
Arable I	208	155	216	39	n.s.
Arable II	493	127	194	53	$p<0{\cdot}05$
Arable III	188	17	19	12	-
Pastoral IV	428	273	431	58	$p<0{\cdot}0001$
Pastoral V	333	114	160	40	n.s.
Marginal upland VI	335	75	129	72	$p<0{\cdot}01$
Upland VII	286	8	14	-	-
Totals	**2271**	**769**	**1163**	**51**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.6. Regional changes in the number of outlying setts, 1988-1997.

Region	Number of squares	Number of outlying setts in the 1980s	Number of outlying setts in the 1990s	Percent change	Significance
North England	170	37	80	116	n.s.
North-west England	72	16	28	75	n.s.
North-east England	121	18	22	22	n.s.
West Midlands	177	96	170	77	$p<0{\cdot}01$
East Midlands	153	40	62	55	n.s.
Central England	91	37	41	11	n.s.
East Anglia	161	10	29	190	$p<0{\cdot}01$
South-west England	205	183	332	81	$p<0{\cdot}0001$
Southern England	131	86	94	9	n.s.
South-east England	159	73	96	32	n.s.
North Scotland	366	27	19	-30	n.s.
South Scotland	208	19	13	-32	n.s.
Mid and north Wales	143	60	89	48	n.s.
South Wales	114	67	88	31	$p<0{\cdot}05$
Totals	**2271**	**769**	**1163**	**51**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.7.7. The change in the number of disused main setts, 1988-1997, by land class group.

Land class group	Number of squares	Number of disused main setts in the 1980s	Number of disused main setts in the 1990s	Percent change	Signif-icance
Arable I	208	21	14	-33	n.s.
Arable II	493	21	12	-43	n.s.
Arable III	188	4	2	-	n.s.
Pastoral IV	428	23	22	-4	n.s.
Pastoral V	333	32	7	-	$p<0{\cdot}0001$
Marginal upland VI	335	8	6	-	n.s.
Upland VII	286	2	1	-	n.s.
Totals	**2271**	**111**	**64**	**-42**	$\boldsymbol{p<0{\cdot}001}$

Table 11.7.8. Regional changes in the number of disused main setts, 1988-1997.

Region	Number of squares	Number of disused main setts in the 1980s	Number of disused main setts in the 1990s	Percent change	Signif-icance
North England	170	5	4	-	n.s.
North-west England	72	6	3	-	n.s.
North-east England	121	6	0	-	n.s.
West Midlands	177	16	9	-	n.s.
East Midlands	153	7	2	-	n.s.
Central England	91	5	2	-	n.s.
East Anglia	161	6	2	-	n.s.
South-west England	205	17	16	-	n.s.
Southern England	131	11	9	-	n.s.
South-east England	159	7	5	-	n.s.
North Scotland	366	6	1	-	n.s.
South Scotland	208	6	2	-	n.s.
Mid and north Wales	143	8	2	-	n.s.
South Wales	114	5	7	-	n.s.
Totals	**2271**	**111**	**64**	**-42**	$\boldsymbol{p<0{\cdot}001}$

11.8 Changes in the size of setts, 1988-1997

Table 11.8.1. Regional changes in the size of main setts, 1988-1997; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Region	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
North England	4·1±1·1	6·7±1·1	1·4±0·4	2·1±0·6	1·9±0·4	1·7±0·4	7·3±1·7	10·5±1·6	n.s.
North-west England	4·0±0·6	7·4±1·3	0·9±0·4	2·0±0·7	1·7±0·8	2·5±1·0	6·6±0·8	11·9±2·6	$p<0{\cdot}05$
North-east England	4·9±1·1	6·3±1·0	3·5±0·9	2·2±0·4	1·3±0·5	1·0±0·3	9·8±1·9	9·5±1·7	n.s.
West Midlands	7·7±1·2	8·7±0·6	2·7±0·5	3·8±0·5	3·1±0·8	3·0±0·5	13·3±1·7	15·5±1·4	$p<0{\cdot}01$
East Midlands	5·3±0·8	6·5±0·8	2·8±0·8	3·4±0·9	4·6±1·8	2·8±0·6	12·7±2·0	12·7±1·8	n.s.
Central England	6·6±1·6	10·1±2·1	2·1±0·5	2·1±0·4	5·7±1·3	2·9±0·6	14·4±2·1	15·1±2·9	n.s.
East Anglia	3·9±1·3	6·6±0·9	4·6±1·3	2·7±1·1	5·3±2·7	3·1±1·5	13·4±3·0	12·5±3·3	n.s.
South-west England	7·1±0·6	9·0±0·7	4·2±0·5	4·3±0·4	3·2±0·4	3·2±0·4	14·4±1·2	16·6±1·3	$p<0{\cdot}001$
Southern England	7·0±0·7	10·3±1·7	2·7±0·5	5·0±1·1	5·2±1·2	4·1±0·7	14·8±1·6	19·4±3·2	$p=0{\cdot}05$
South-east England	6·1±0·5	6·5±0·7	3·7±0·5	4·7±0·7	2·7±0·5	3·2±0·6	12·5±0·9	14·5±1·3	$p<0{\cdot}05$
North Scotland	5·3±1·7	5·6±1·3	2·2±0·8	3·3±0·7	1·4±1·3	1·7±0·6	9·0±2·3	10·6±2·6	n.s.
South Scotland	4·1±0·7	5·3±0·8	1·6±0·4	2·1±0·5	1·9±0·5	1·2±0·4	7·6±1·2	8·6±1·0	n.s.
Mid and north Wales	4·8±0·7	9·7±1·0	2·2±0·4	2·8±0·6	3·6±1·2	2·3±0·6	10·6±1·7	14·8±1·8	$p=0{\cdot}01$
South Wales	6·0±0·7	7·5±0·7	2·4±0·5	2·2±0·5	2·1±0·7	2·6±0·9	11·0±1·3	12·8±1·7	$p<0{\cdot}001$
Totals	**6·0±0·3**	**8·2±0·3**	**3·0±0·2**	**3·6±0·2**	**3·1±0·3**	**2·9±0·2**	**12·0±0·5**	**14·6±0·5**	$\boldsymbol{p<0{\cdot}0001}$

Table 11.8.2. The change in the size of annexe setts, 1988-1997, by land class group; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Land class group	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
Arable I	2·0±0·4	2·5±0·3	1·2±0·3	1·4±0·2	2·2±0·4	1·6±0·3	5·4±0·6	5·5±0·4	n.s.
Arable II	2·3±0·4	2·3±0·4	2·0±0·5	1·2±0·2	2·4±0·4	1·3±0·2	6·1±0·7	4·9±0·6	n.s.
Arable III	0·5±0·5	1·6±0·5	2·0±0·0	0·9±0·3	1·0±1·0	2·2±1·0	3·5±0·5	4·7±0·7	-
Pastoral IV	2·2±0·3	2·9±0·3	1·4±0·2	2·0±0·2	2·1±0·4	2·1±0·3	5·7±0·4	6·7±0·6	$p<0{\cdot}01$
Pastoral V	0·8±0·3	1·8±0·3	1·7±0·5	1·4±0·3	2·5±0·6	1·4±0·3	5·2±0·9	4·6±0·5	n.s.
Marginal upland V1	1·1±0·5	1·8±0·2	0·3±0·2	1·7±0·5	1·3±0·7	0·4±0·2	2·7±1·1	3·9±0·6	n.s.
Upland VII	-	-	-	-	-	-	-	-	-
Totals	**1·9±0·2**	**2·4±0·2**	**1·5±0·2**	**1·6±0·1**	**2·1±0·2**	**1·6±0·1**	**5·5±0·3**	**5·7±0·3**	$\boldsymbol{p<0{\cdot}01}$

Table 11.8.3. Regional changes in the size of annexe setts, 1988-1997; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Region	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Signif-icance
North England	1·7±0·8	2·4±1·3	1·9±1·1	2·7±2·1	1·1±0·7	2·0±2·0	4·7±1·2	7·1±1·8	n.s.
North-west England	0	0·7±0·6	0	1·3±0·8	3·3±1·1	2·3±0·8	3·3±1·2	4·2±1·3	n.s.
North-east England	1·9±0·5	3·1±1·1	2·1±0·7	1·1±0·5	2·6±0·7	1·4±0·6	6·5±0·5	5·6±1·8	n.s.
West Midlands	1·2±0·5	2·1±0·3	1·4±0·5	1·8±0·2	2·9±0·8	1·5±0·3	5·4±1·0	5·4±0·8	n.s.
East Midlands	1·5±0·6	1·8±0·4	0·8±0·7	0·6±0·3	1·0±0·5	1·0±0·4	3·4±0·6	3·4±0·7	n.s.
Central England	0·7±0·4	2·8±0·8	0·9±0·5	1·6±0·5	3·4±0·9	1·3±0·4	5·1±0·8	5·6±1·4	n.s.
East Anglia	2·0±0·0	2·1±1·0	0	1·5±0·9	0	0·7±0·5	2·0±0·0	4·3±1·5	n.s.
South-west England	2·0±0·3	2·9±0·3	1·5±0·3	1·9±0·3	2·1±0·5	1·8±0·3	5·7±0·4	6·6±0·8	$p<0{\cdot}05$
Southern England	3·0±1·0	2·1±0·4	1·4±0·5	1·5±0·3	2·4±0·8	2·7±0·7	6·7±1·5	6·3±1·1	n.s.
South-east England	2·6±0·4	2·1±0·3	1·7±0·5	1·6±0·3	1·8±0·5	1·3±0·3	6·1±0·7	5·0±0·8	n.s.
North Scotland	0·2±0·3	0	1·3±0·8	2·5±1·5	1·0±1·0	2·0±2·0	2·5±1·5	4·5±1·9	-
South Scotland	1·0±0·0	1·3±0·4	1·0±0·0	1·2±0·3	1·5±1·5	1·0±0·4	3·5±1·5	3·4±0·9	-
Mid and north Wales	1·1±0·4	2·2±0·3	2·3±0·8	1·3±0·5	2·2±0·8	0·9±0·4	5·5±1·6	4·4±0·9	n.s.
South Wales	3·0±0·9	4·2±1·1	0·8±0·2	1·7±0·7	1·8±0·9	2·8±0·6	5·7±0·7	7·8±1·4	n.s.
Totals	**1·9±0·2**	**2·4±0·2**	**1·4±0·2**	**1·6±0·1**	**2·2±0·2**	**1·6±0·1**	**5·5±0·3**	**5·7±0·3**	$p<0{\cdot}01$

Table 11.8.4. The change in the size of subsidiary setts, 1988-1997, by land class group; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Land class group	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Signif-icance
Arable I	1·0±0·2	1·5±0·2	1·4±0·2	1·2±0·1	2·2±0·3	2·1±0·2	4·6±0·3	4·8±0·2	n.s.
Arable II	1·0±0·2	2·0±0·2	1·1±0·2	1·4±0·2	1·9±0·3	1·6±0·3	4·1±0·2	5·0±0·3	n.s.
Arable III	0·3±0·3	1·2±0·3	2·0±0·7	1·5±0·3	1·9±0·7	1·4±0·6	4·1±0·6	4·0±0·4	n.s.
Pastoral IV	1·3±0·2	1·5±0·1	1·5±0·2	1·7±0·1	1·7±0·2	2·2±0·3	4·5±0·2	5·4±0·3	$p<0·01$
Pastoral V	0·6±0·1	1·4±0·2	1·3±0·3	1·5±0·2	2·0±0·3	1·5±0·2	4·0±0·3	4·4±0·2	n.s.
Marginal upland VI	0·9±0·2	1·9±0·3	1·6±0·3	1·8±0·3	1·7±0·3	1·3±0·4	4·2±0·3	5·1±0·4	n.s.
Upland VII	0·5±0·5	1·0±0·4	1·5±0·5	1·5±0·3	1·6±0·6	1·5±0·4	3·6±0·6	4·0±0·3	n.s.
Totals	**1·0±0·1**	**1·6±0·1**	**1·4±0·1**	**1·5±0·1**	**1·9±0·1**	**1·8±0·1**	**4·3±0·1**	**5·0±0·1**	**$p=0·0001$**

Table 11.8.5. Regional changes in the size of subsidiary setts, 1988-1997; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Region	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
North England	0·3±0·2	1·3±0·3	0·8±0·4	1·8±0·4	1·5±0·4	1·5±0·5	3·9±0·3	4·7±1·2	n.s.
North-west England	0·7±0·3	1·3±0·4	1·6±0·6	1·4±0·4	1·8±0·5	1·5±0·6	4·1±0·5	4·2±1·3	n.s.
North-east England	1·0±0·6	2·0±0·6	0·7±0·6	2·4±1·0	0·7±0·6	1·2±0·4	2·3±0·2	5·6±1·8	-
West Midlands	0·9±0·2	1·6±0·2	1·7±0·3	1·4±0·2	1·7±0·4	2·1±0·3	4·3±0·2	5·0±0·8	n.s.
East Midlands	1·0±0·3	2·2±0·4	0·7±0·3	0·9±0·2	1·8±0·5	0·9±0·4	3·6±0·2	4·0±0·8	n.s.
Central England	0·3±0·2	2·1±0·5	1·3±0·6	1·2±0·3	2·4±0·6	1·6±0·5	4·0±0·3	4·8±1·2	n.s.
East Anglia	0·5±0·5	1·7±0·4	1·0±1·0	1·4±0·4	2·0±2·0	1·4±0·7	3·5±0·3	4·5±1·6	n.s.
South-west England	1·1±0·3	1·8±0·2	1·5±0·2	1·6±0·2	1·8±0·3	2·1±0·3	4·7±0·2	5·6±0·7	$p<0{\cdot}01$
Southern England	0·8±0·3	1·2±0·2	1·5±0·3	1·8±0·3	2·3±0·5	2·3±0·3	5·0±0·4	5·3±0·9	n.s.
South-east England	1·3±0·2	1·6±0·3	1·1±0·2	1·2±0·2	1·9±0·4	2·1±0·3	4·3±0·2	5·0±0·8	n.s.
North Scotland	0·5±0·4	0·9±0·3	2·1±0·6	2·0±0·5	2·0±0·9	1·3±0·4	4·6±0·5	4·2±1·8	n.s.
South Scotland	0·5±0·2	0·7±0·2	1·3±0·3	1·2±0·3	1·3±0·5	2·3±0·5	3·2±0·3	4·2±1·1	n.s.
Mid and north Wales	0·8±0·2	2·1±0·3	1·5±0·4	1·4±0·2	1·6±0·3	1·1±0·4	3·8±0·3	4·6±1·0	n.s.
South Wales	0·9±0·3	1·1±0·3	1·6±0·5	1·7±0·3	2·4±0·5	1·6±0·4	4·9±0·3	4·3±0·8	n.s.
Totals	**1·0±0·1**	**1·6±0·1**	**1·4±0·1**	**1·5±0·1**	**1·9±0·1**	**1·8±0·1**	**4·3±0·1**	**5·0±0·1**	$p<0{\cdot}0001$

Table 11.8.6. The change in the size of outlying setts, 1988-1997, by land class group; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Land class group	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
Arable I	0·5±0·1	0·6±0·1	0·6±0·1	0·6±0·1	0·8±0·1	0·5±0·1	1·8±0·1	1·7±0·1	n.s.
Arable II	0·4±0·1	0·7±0·1	0·4±0·1	0·5±0·1	0·8±0·1	0·5±0·1	1·6±0·1	1·7±0·1	$p<0·05$
Arable III	0·8±0·3	0·5±0·2	0·3±0·1	0·6±0·2	1·3±0·4	0·5±0·2	2·4±0·4	1·6±0·2	n.s.
Pastoral IV	0·5±0·1	0·6±0·0	0·5±0·1	0·6±0·0	0·8±0·1	0·5±0·1	1·8±0·1	1·6±0·1	n.s.
Pastoral V	0·3±0·1	0·6±0·1	0·5±0·1	0·6±0·1	0·9±0·1	0·5±0·1	1·8±0·1	1·7±0·1	n.s.
Marginal upland VI	0·4±0·1	0·5±0·1	0·8±0·1	0·6±0·1	0·4±0·1	0·5±0·1	1·6±0·1	1·6±0·1	n.s.
Upland VII	0·3±0·2	0·3±0·2	0·6±0·5	0·7±0·2	0·8±0·4	0·3±0·3	1·7±0·2	1·3±0·2	n.s.
Totals	**0·4±0·0**	**0·6±0·0**	**0·5±0·0**	**0·5±0·0**	**0·8±0·1**	**0·5±0·0**	**1·7±0·0**	**1·7±0·0**	**n.s.**

Table 11.8.7. Regional changes in the size of outlying setts, 1988-1997; figures are means ±s.e. The statistical tests are for comparisons between the total number of holes in the 1980s and 1990s.

Region	Number of well-used holes in the 1980s	Number of well-used holes in the 1990s	Number of partially-used holes in the 1980s	Number of partially-used holes in the 1990s	Number of disused holes in the 1980s	Number of disused holes in the 1990s	Total number of holes in the 1980s	Total number of holes in the 1990s	Significance
North England	0·5±0·1	0·7±0·1	0·6±0·1	0·4±0·1	0·8±0·2	0·3±0·1	1·8±0·3	1·5±0·4	n.s.
North-west England	0·3±0·1	0·7±0·2	0·6±0·2	0·5±0·2	0·6±0·2	0·4±0·2	1·4±0·2	1·6±0·5	n.s.
North-east England	0·5±0·2	0·4±0·2	0·4±0·2	0·9±0·3	0·9±0·2	1·1±0·3	1·8±0·2	2·5±0·8	n.s.
West Midlands	0·5±0·1	0·6±0·1	0·5±0·1	0·7±0·1	0·9±0·2	0·3±0·1	1·8±0·2	1·6±0·2	n.s.
East Midlands	0·2±0·1	0·6±0·1	0·6±0·2	0·6±0·1	0·7±0·2	0·8±0·2	1·6±0·1	1·8±0·4	n.s.
Central England	0·3±0·1	0·9±0·2	0·4±0·1	0·5±0·1	0·6±0·1	0·4±0·1	1·4±0·1	1·7±0·4	n.s.
East Anglia	0·7±0·2	0·7±0·2	0·4±0·3	0·7±0·2	1·1±0·4	0·4±0·2	1·8±0·2	1·5±0·5	n.s.
South-west England	0·7±0·1	0·7±0·1	0·4±0·1	0·5±0·0	0·6±0·1	0·5±0·1	1·7±0·1	1·6±0·2	n.s.
Southern England	0·3±0·1	0·6±0·1	0·6±0·1	0·6±0·1	0·9±0·2	0·6±0·2	1·9±0·2	1·8±0·3	n.s.
South-east England	0·4±0·1	0·6±0·1	0·5±0·1	0·7±0·1	1·0±0·2	0·6±0·1	1·9±0·2	1·8±0·3	n.s.
North Scotland	0·2±0·2	0·3±0·1	0·9±0·3	0·5±0·2	0·8±0·4	0·4±0·2	1·9±0·4	1·3±0·5	n.s.
South Scotland	0·3±0·2	0·3±0·1	0·1±0·1	0·7±0·2	1·6±0·3	1·3±0·3	2·0±0·2	1·9±0·5	n.s.
Mid and north Wales	0·3±0·1	0·6±0·1	0·6±0·1	0·6±0·1	0·6±0·1	0·4±0·1	1·5±0·1	1·6±0·3	n.s.
South Wales	0·4±0·1	0·6±0·1	0·8±0·2	0·6±0·1	0·6±0·2	0·3±0·1	1·7±0·1	1·4±0·3	n.s.
Totals	**0·4±0·0**	**0·6±0·0**	**0·5±0·0**	**0·5±0·0**	**0·8±0·1**	**0·5±0·0**	**1·7±0·0**	**1·7±0·0**	**n.s.**

11.9 Changes in the levels of persecution at annexe, subsidiary, outlying and disused main setts, 1988-1997

Table 11.9.1. Changes in the number of annexe setts showing signs of digging, 1988-1997, by land class group.

Land class group	Number of setts dug in the 1980s	Total number of annexe setts	Percent annexe setts dug in the 1980s	Number of setts dug in the 1990s	Total number of annexe setts	Percent annexe setts dug in the 1990s	Significance
Arable I	4	50	8	0	92	0	-
Arable II	3	35	9	1	72	1	-
Arable III	0	2	-	1	8	-	-
Pastoral IV	1	74	1	1	157	1	-
Pastoral V	4	27	15	3	41	7	-
Marginal upland VI	1	8	-	0	29	0	-
Upland VII	0	0	-	0	1	-	-
Totals	**13**	**196**	**7**	**6**	**400**	**2**	**n.s.**

Table 11.9.2. Changes in the number of subsidiary setts showing signs of digging, 1988-1997, by land class group.

Land class group	Number of setts dug in the 1980s	Total number of subsidiary setts	Percent subsidiary setts dug in the 1980s	Number of setts dug in the 1990s	Total number of subsidiary setts	Percent subsidiary setts dug in the 1990s	Significance
Arable I	2	90	2	*1*	*154*	*1*	-
Arable II	2	65	3	3	98	3	-
Arable III	1	8	-	0	14	0	-
Pastoral IV	4	138	3	2	242	1	-
Pastoral V	4	63	6	6	89	7	-
Marginal upland VI	0	38	0	1	49	2	-
Upland VII	0	5	-	0	11	0	-
Totals	**13**	**407**	**3**	**13**	**657**	**2**	**n.s.**

Table 11.9.3. Changes in the number of outlying setts showing signs of digging, 1988-1997, by land class group.

Land class group	Number of setts dug in the 1980s	Total number of outlier setts	Percent outlier setts dug in the 1980s	Number of setts dug in the 1990s	Total number of outlier setts in the 1990s	Percent outlier setts dug in the 1990s	Significance
Arable I	3	146	2	1	216	<1	-
Arable II	3	122	2	1	194	1	-
Arable III	1	15	7	0	19	0	-
Pastoral IV	1	261	<1	2	431	0	-
Pastoral V	7	109	6	2	160	1	-
Marginal upland VI	0	72	0	1	129	1	-
Upland VII	0	8	-	1	14	7	-
Totals	**15**	**733**	**2**	**8**	**1163**	**1**	**n.s.**

Table 11.9.4. Changes in the number of disused main setts showing signs of digging, 1988-1997, by land class group.

Land class group	Number of setts dug in the 1980s	Total number of setts	Percent disused main setts dug in the 1980s	Number of setts dug in the 1990s	Total number of setts	Percent disused main setts dug in the 1980s	Significance
Arable I	3	21	14	1	14	7	-
Arable II	1	21	5	0	12	0	-
Arable III	0	4	-	2	2	-	-
Pastoral IV	0	23	0	1	22	5	-
Pastoral V	2	32	6	0	7	-	-
Marginal upland VI	1	8	-	0	6	-	-
Upland VII	0	2	-	0	1	-	-
Totals	**7**	**111**	**7**	**4**	**64**	**6**	**n.s.**

Table 11.9.5. Regional changes in the number of setts other than active main setts (i.e. annexe, subsidiary, outlying and disused main setts combined) showing signs of digging, 1988-1997.

Region	Number of setts dug in the 1980s	Total number of other setts	Percent other setts dug in the 1980s	Number of setts dug in the 1990s	Total number of other setts	Percent other setts dug in the 1990s	Significance
North England	5	62	8	6	116	5	-
North-west England	4	37	11	4	58	7	-
North-east England	3	41	7	1	38	3	-
West Midlands	7	168	4	3	327	1	-
East Midlands	3	77	4	3	105	3	-
Central England	2	70	3	0	85	0	-
East Anglia	1	19	5	1	61	2	-
South-west England	3	355	1	3	657	<1	-
Southern England	3	154	2	2	214	1	-
South-east England	6	140	4	1	209	<1	-
North Scotland	0	45	0	0	33	0	-
South Scotland	2	42	5	1	38	3	-
Mid and north Wales	7	101	7	4	172	2	-
South Wales	2	132	2	3	171	2	-
Totals	**48**	**1447**	**3**	**32**	**2284**	**1**	**n.s.**

Table 11.9.6. Changes in the number of annexe setts showing signs of hole blocking, 1988-1997, by land class group.

Land class group	Number of setts blocked in the 1980s	Total number of annexe setts	Percent annexe setts blocked in the 1980s	Number of setts blocked in the 1990s	Total number of annexe setts	Percent annexe setts blocked in the 1990s	Significance
Arable I	7	50	14	8	92	9	-
Arable II	5	35	14	5	72	7	-
Arable III	0	2	-	0	8	-	-
Pastoral IV	2	74	3	12	157	8	-
Pastoral V	1	27	4	1	41	2	-
Marginal upland VI	0	8	-	2	29	7	-
Upland VII	0	0	-	0	1	-	-
Totals	**15**	**196**	**8**	**28**	**400**	**7**	**n.s.**

Table 11.9.7. Changes in the number of subsidiary setts showing signs of hole blocking, 1988-1997, by land class group.

Land class group	Number of setts blocked *in the* 1980s	Total number of subsidiary setts	Percent subsidiary setts blocked in the *1980s*	Number of setts blocked in the *1990s*	Total number of subsidiary setts	Percent subsidiary setts blocked in *the 1990s*	Significance
Arable I	8	90	9	11	154	7	-
Arable II	8	65	12	13	98	13	-
Arable III	0	8	-	1	14	7	-
Pastoral IV	9	138	7	8	242	3	-
Pastoral V	4	63	6	6	89	7	-
Marginal upland VI	0	38	0	2	49	4	-
Upland VII	1	5	-	0	11	0	-
Totals	**30**	**407**	**7**	**41**	**657**	**6**	**n.s.**

Table 11.9.8. Changes in the number of outlying setts showing signs of hole blocking, 1988-1997, by land class group.

Land class group	Number of setts blocked in the 1980s	Total number of outlier setts	Percent outlier setts blocked in the 1980s	Number of setts blocked in the 1990s	Total number of outlier setts	Percent outlier setts blocked in the 1990s	Significance
Arable I	4	146	3	3	216	1	-
Arable II	5	122	4	7	194	4	-
Arable III	1	15	7	2	19	11	-
Pastoral IV	11	261	4	10	431	2	-
Pastoral V	3	109	3	1	160	1	-
Marginal upland VI	3	72	4	1	129	1	-
Upland VII	0	8	-	0	14	0	-
Totals	**27**	**733**	**4**	**24**	**1163**	**2**	**n.s.**

Table 11.9.9. Changes in the number of disused main setts showing signs of hole blocking, 1988-1997, by land class group.

Land class group	Number of setts blocked in the 1980s	Total number of disused main setts	Percent disused main setts blocked in the 1980s	Number of setts blocked in the 1990s	Total number of disused main setts	Percent disused main setts blocked in the 1990s	Significance
Arable I	3	21	14	3	14	21	-
Arable II	7	21	33	1	12	8	-
Arable III	0	4	-	2	2	-	-
Pastoral IV	2	23	9	2	22	9	-
Pastoral V	5	32	16	0	7	-	-
Marginal upland VI	1	8	-	1	6	-	-
Upland VII	0	2	-	0	1	-	-
Totals	**18**	**111**	**16**	**9**	**64**	**14**	**n.s.**

Table 11.9.10. Regional changes in the number of setts other than active main setts (i.e. annexe, subsidiary, outlying and disused main setts combined) showing signs of hole blocking, 1988-1997.

Region	*Number* of setts blocked in the 1980s	Total number of other setts	Percent other setts blocked in the 1980s	Number *of setts* blocked in the 1990s	Total *number* of other setts	Percent other setts blocked in the 1990s	Significance
North England	4	62	6	5	116	4	-
North-west England	3	37	8	2	58	3	-
North-east England	1	41	2	2	38	5	-
West Midlands	21	168	13	21	327	6	-
East Midlands	6	78	8	11	105	10	-
Central England	5	70	7	6	85	7	-
East Anglia	3	19	16	1	61	2	-
South-west England	20	355	6	25	657	4	-
Southern England	12	157	8	6	214	3	-
South-east England	10	140	7	9	209	4	-
North Scotland	0	45	0	1	33	3	-
South Scotland	0	42	0	4	38	11	-
Mid and north Wales	4	101	4	3	172	2	-
South Wales	1	132	1	6	171	4	-
Totals	**90**	**1447**	**6**	**102**	**2284**	**4**	**n.s.**

Table 11.9.11. Changes in the number of setts other than active main setts (i.e. annexe, subsidiary, outlying and disused main setts combined) affected by snaring, 1988-1997, by land class group.

Land class group	Number of setts snared in the 1980s	Total number of other setts	Percent other setts snared in the 1980s	Number of setts snared in the 1990s	Total number of other setts	Percent other setts snared in the 1990s
Arable I	3	307	1	1	476	<1
Arable II	1	243	<1	1	376	<1
Arable III	1	29	3	0	43	0
Pastoral IV	1	496	<1	0	852	0
Pastoral V	3	231	1	0	297	0
Marginal upland VI	2	126	2	0	213	0
Upland VII	0	15	0	0	27	0
Totals	**11**	**1447**	**1**	**2**	**2284**	**<1**

11.10 Instruction sheets and recording forms for group size / field sign pilot study.

11.10.1 Data sheet for recording latrine details

(badger group ref:)	Date of latrine survey:	Surveyor:
Coords:		No. nights baitmarked:

Latrine *Number*	Number of pits	Number of faeces	Number of fresh faeces	No. of faeces with pellets (colour, if more than one group studied)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

Further comments overleaf.

11.10.2 Data sheet for recording group size

Badger group size recording form - head count data

Name:

Sett Watched	grid ref.	day 1 watching : Date	max. number of adults seen at *one time*	total number of adults believed to have been seen (if different)	max. number of cubs seen at one time
A					
B					
C					
D					
E					

Sett Watched	grid ref.	day 2 watching : Date	max. number of adults seen at one time	total number of adults believed to have been seen (if different)	max. number of cubs seen at one time
A					
B					
C					
D					
E					

Sett Watched	grid ref.	day 3 watching : Date	max. number of adults seen at one time	total number of adults believed to have been seen (if different)	max. number of cubs seen at one time
A					
B					
C					
D					
E					

Sett Watched	grid ref.	day 4 watching: Date	max. number of adults seen at one time	total number of adults believed to have been seen (if different)	max. number of cubs seen at one time
A					
B					
C					
D					
E					

11.10.2 Data sheet for recording group size (cont)

P.T.O.

Comments

Details of any other setts watched:

Sett Watched	grid. ref.	Date	max. number of adults seen at one time	total number of adults believed to have been seen (if different)	max. number of cubs seen at one time

11.10.3 Data sheet for recording sett details

Badger Sett recording form

(Badger group ref:)	Date:	Surveyor:	Land Class:
Coords:			

Sett number	no. active holes	no. partially-used holes	no. disused holes	surface soil type	spoil soil type (if different)	slope (1, 2, 3)
A						
B						
C						
D						
E						
F						
G						
H						
I						
J						
K						
L						
M						
N						
O						
P						
Q						
R						
S						
T						
U						
V						
W						

Comments:

11.10.4 Baitmarking and latrine survey instructions

<u>Guidelines for Baitmarking</u>

The Technique

Baitmarking is used to reveal the location of the territory boundary of a social group of badgers. Badgers mark the territory by depositing faeces in latrines which delineate the boundary. These are often (but not always) in prominent positions at linear habitat features such as hedgerows, or the boundary between one habitat and another e.g. the edge of a wood. The principle is to feed the badgers indigestible but inert coloured markers, mixed in with a bait which is attractive to them. All the latrines in the area are then checked for the coloured markers.

The Mixture

To make the mixture you need:

10 litre bucket
8 litre peanuts
0.5 litres of plastic pellets
1 jar / tin golden syrup

1. Pour the peanuts into the bucket and level off the surface.

2. Add the plastic pellets evenly over the surface to form a layer about one centimetre deep.

3. Mix the pellets and peanuts. Insert a long handled spoon into the middle of the peanuts and make several circular sweeps of the bucket until most of the pellets have disappeared from the surface. **Do not** mix too much as the pellets will all end up near the bottom of the bucket.

4. Add the syrup. It is easier to warm the jar / tin of syrup first in a bowl of hot water. Pour half the warm syrup evenly over the surface of the mixtures so that the surface is completely covered. Leave for a few minutes to allow the syrup to sink through the mixture, then stir. Finally add the rest of the syrup and continue mixing.

[if it is not possible to mix the contents towards the bottom of the bucket, do not worry as this can be done at the sett when the rest of the contents of the bucket have been laid around the sett. Alternatively, you may find it easier to carry out the preparation in stages i.e. make up half the mixture first, followed by the second half afterwards]

The Fieldwork

The reason for carrying out baitmarking in the period February-April is because badgers actively mark their territorial boundaries at this time. The baitmarking should be concentrated at the main sett for each group of badgers. Use a different colour for each group, making sure the different colours do not get mixed up. When studying more than one badger group, a different colour should be used for each one so that the marker returns from the different groups can be distinguished in the latrines.

11.10.4 Continued

Steps

1. Lay the bait. Make a hole in the ground near each of the sett entrances with the heel of your boot, and place in it a large wooden spoonful of the mixture. It is then best to cover this with earth or a large stone to prevent birds and small mammals from eating it. The stones can be quite large as badgers will easily move weights up to 10kg.

2. Twenty or thirty such bait points should be laid around the sett each day, located around all of the entrances. This is to ensure that all of the badgers in the sett take some of the bait. Change the location of the bait points as often as possible to ensure this. Also throw some bait down the most active holes.

3. Try to continue with the feeding for 14 days

4. Try to place bait at the sett every day if possible.

Recording the Data

- To ensure that as many latrines as possible are found, it is best to carry out a survey of the area before the bait is placed, if you have the time. After the baiting period, the area should then be resurveyed, visiting all the known latrines and checking for any new or missed ones. Any faeces in the latrines should be checked for the presence of coloured markers. To make sure no markers are missed, the faeces should be spread out with a stick.

- When searching for bait returns after laying the bait, care should be taken to survey to a distance away from the sett beyond which no more markers are found.

- Mark the position of the main sett where the bait was placed on the map. Fill in the latrine recording form on the day that you do the final survey for pellets, after the period of laying bait at the sett, so that a 'snapshot' is taken. Mark all latrines found on the map, and number them. On the latrine recording form, note the details of the latrine as directed on the form i.e. the number of pits in the latrine, number of droppings, number of fresh droppings and the number of droppings containing pellets (and the colour, if more than one group has been marked). Also record on how many days bait was placed at the sett in the 'no. nights baitmarked' column.

- On the map, draw a line from the main sett where the bait was placed to each of the latrines where the bait was recovered, using a fine-tipped pencil. By drawing a line around the outermost points, a minimum territorial area is produced.

In some areas, often where the density of badgers is low, few latrines will be found. In cases such as this, do not attempt to produce a territory boundary, simply indicate on the map where the latrines are.

11.11 Estimate of badger numbers - confidence interval calculations

11.11.1 Calculation of the regression-predicted confidence intervals around the estimate of badger numbers in the 1980s

Land class group	Estimated number of main setts	Mean group size lower 95% CI	Mean group size upper 95% CI	Total badgers - 95% CI	Total badgers - 95% CI
Arable I	6346	6.02	5.65	25,869	36,349
Arable I	8925	3.78	5.58	33,699	49,834
Arable I	1706	3.02	4.89	5161	8340
Pastoral IV	13,271	4.28	6.17	58,626	84,635
Pastoral V	5928	3.61	5.53	21,418	32,791
Marginal upland VI	3375	3.20	5.07	10,793	17,117
Upland VII	308	2.56	4.39	790	1353
Totals				**156356**	**230418**

11.11.2 Calculation of the regression-predicted confidence intervals around the estimate of badger numbers in the 1990s

Land class group	Estimated number of main setts	Mean group size lower 95% CI	Mean group size upper 95% CI	Total badgers - 95% CI	Total badgers - 95% CI
Arable I	6366	6.21	8.72	33,387	45,041
Arable I	11381	5.33	7.31	60,685	83,236
Arable I	16001	3.57	5.4	5708	8635
Pastoral IV	6743	5.50	7.47	92,025	12,498
Pastoral V	8586	5.06	6.84	43,450	58,690
Marginal upland VI	4816	4.91	6.61	23,661	31,838
Upland VII	749	3.54	5.06	2649	3790
Totals				**261,566**	**356,218**

11.12 Published work

Wilson, G., Harris, S. & McLaren, G. (1997) *Changes in the British badger population, 1988 to 1997*. (142 pages). London: Peoples Trust for Endangered Species.

ISBN 1 85580 018 7

Changes in the British badger population, 1988 to 1997

Gavin Wilson, Stephen Harris
and Graeme McLaren

School of Biological Sciences,
University of Bristol,
Woodland Road, Bristol, BS8 1UG

PEOPLE'S TRUST
FOR ENDANGERED SPECIES

LONDON